



Analysis of marine protected areas – in the Danish part of the North Sea and the Central Baltic around Bornholm

Part 2: Ecological and economic value, human pressures, and MPA selection

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Part 2: Ecological and economic value, human pressures, and MPA selection



DTU Aqua report no. 325-2017
By DTU Aqua, DCE, DHI and GEUS



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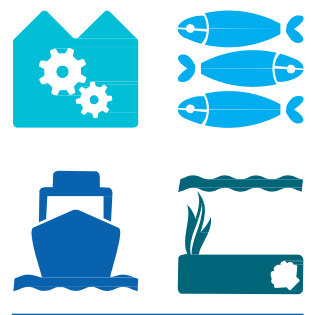
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6. Overall evaluation of economical values

6.1 Introduction

Human activities and exploitation of marine resources are becoming an increasing pressure factor when marine protected areas and marine spatial planning are endeavoured. Societal benefit of these resources is a key issue when addressing the sustainability of marine and coastal areas.

In order to design and implement a robust management plan, valid and detailed data on these pressure factors are needed. It is important to address the economic value of the human activities together with an evaluation of their impact on benthic habitats as a means in the future planning of new protected areas.

Aggregate extraction areas are one example of human activity that has economical value on the societal level. Society's need for these aggregates can change from time to time following the economic growth of the country or the need for some offshore infrastructure. Therefore, some areas which today are evaluated with having low value may be of high value in the future and vice versa. Similar examples may be given for other areas used for infrastructures like wind farms. In the following chapter a long list of human impact factors are addressed and evaluated.

6.2 Fisheries

6.2.1 Value of landings

The spatial distribution of the value of the landings from the Danish fisheries in the two zones was derived by combining information from a number of sampling schemes: 1) Logbook data containing information about the species composition of the landings, fishing gear, fishing ground, and fishing effort. Logbooks are mandatory for vessels larger than 10 meters in the North Sea and Skagerrak, and 8 meters in the Baltic Sea. 2) Sales slips census data containing information from first hand buyers about the amounts landed in tons and value per species, 3) VMS (Vessel Monitoring System) data providing hourly information about the position, speed, and course of each vessel. VMS data are mandatory for all vessels larger than 12 meter in the North Sea and Skagerrak, and 10 meter in the Baltic Sea. These three sources of data can be combined to show the distribution of the value, weight and fishing effort by major fleet categories (Bastardie et al. 2010). All the basic information was provided by the Danish Fish Agency and processed by DTU Aqua.

Fisheries data are reported to the EU by major fleet and gear categories following the Data Collection Framework (DCF) provided in COMMISSION IMPLEMENTING DECISION (EU) 2016/1251 of 12 July 2016 where different fishing fleets are defined based on combinations of area, gear and target species. In the North Sea a total of ten EU DCF fleets were considered: beam trawl, otter trawl, Scottish seine, Danish seine, lines, set gillnets, set longlines, traps, pelagic trawl and unknown gear types. In the Baltic seven fleets were included: otter trawl, Scottish seine, Danish seine, set gillnets, pelagic trawl, drifting longlines and unknown gears.

Relative average value of the landings from the two zones is shown by major gear category in Figure 1. In both areas otter trawling on the bottom provides the largest contribution to the value landed followed by pelagic trawl. However, where these two gear types account for 99% of the value generated in the Baltic zone, they account for only 64% of the first hand value of the catch in the North Sea and Skagerrak. The resulting spatial distributions of landed value from the two zones are shown for the different fleets in Figure 2 to Figure 11 and Figure 14 to Figure 19, respectively. Overall they show large differences in the spatial distribution across fleets. In the North Sea. The beam trawl fleet is fishing for brown shrimp outside the Danish Wadden Sea. The otter trawl, pelagic trawl and gillnet fisheries are widespread, while the Danish and Scottish seines are concentrated in the northern part. The remaining fisheries are patchy and less economically important. In the Baltic, otter trawl and pelagic trawl are the dominating gear types. Drifting

longlines are concentrated in particular areas south of Bornholm, while the remaining gears are of little significance in the area. Data on fishing effort and landed weight were also made available. They will be included in the GIS maps accompanying the final report, but have not been used in the following and are therefore not presented. However, there are only minor differences in the spatial distribution of landed value, landed weight and fishing effort.

6.2.2 Bottom impacts

Mobile fishing gears with bottom contact may impact benthic organisms in the path of the gear. To account for the negative pressure such gears exert on benthic communities, international data on surface and sub-surface abrasion intensity were included in the analysis. The intensity of the pressure was expressed as the area swept by gear parts in contact with (surface abrasion) or penetrating the seabed (sub-surface abrasion) per year relative to the size of the area considered, the so-called swept area ratios (SAR). Maps of surface and sub-surface abrasion were available from ICES for the North Sea and from the EU funded BENTHIS and Baltic Boost projects for the Baltic. For the North Sea the maps covered the fishing activities of the entire international fleet, while for the Baltic only data from Denmark, Sweden and Germany were available, see Figure 12, Figure 13 and Figure 20, Figure 21, respectively. This ignores the Polish, Lithuanian, Estonian, and Latvian vessels that may operate in the Danish zone, but no total or spatial data are available. In the North Sea surface and sub-surface abrasion is most intensive in the northern part of the area, while in the Baltic surface abrasion is found in most of the area, but reach the lowest values in the southwestern part where the bottom is hard and the large Natura 2000 area is situated.

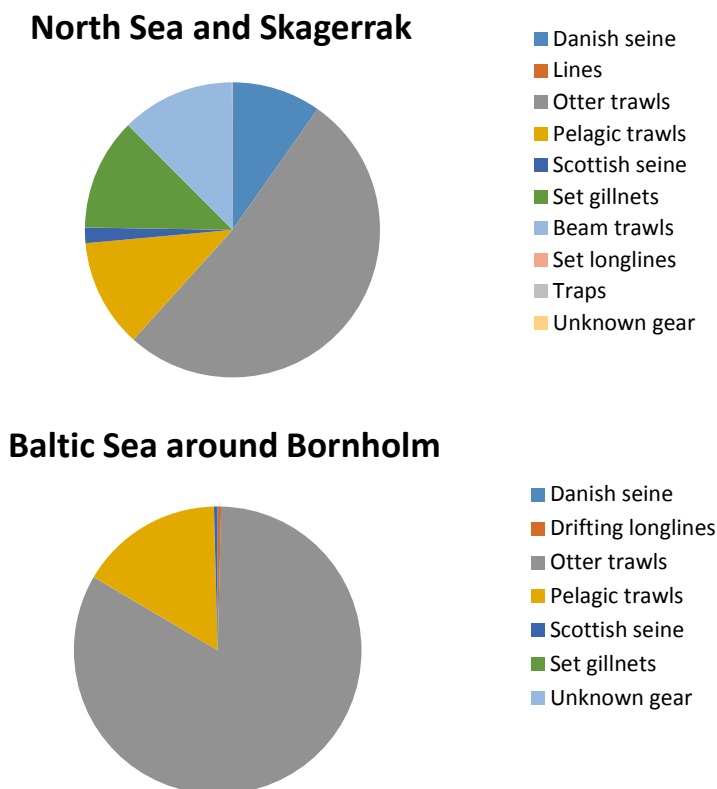


Figure 1 Relative value of Danish landings in the Danish part of the North Sea and Skagerrak and in the Danish part of the Baltic Sea around Bornholm (data from 2012-2016).

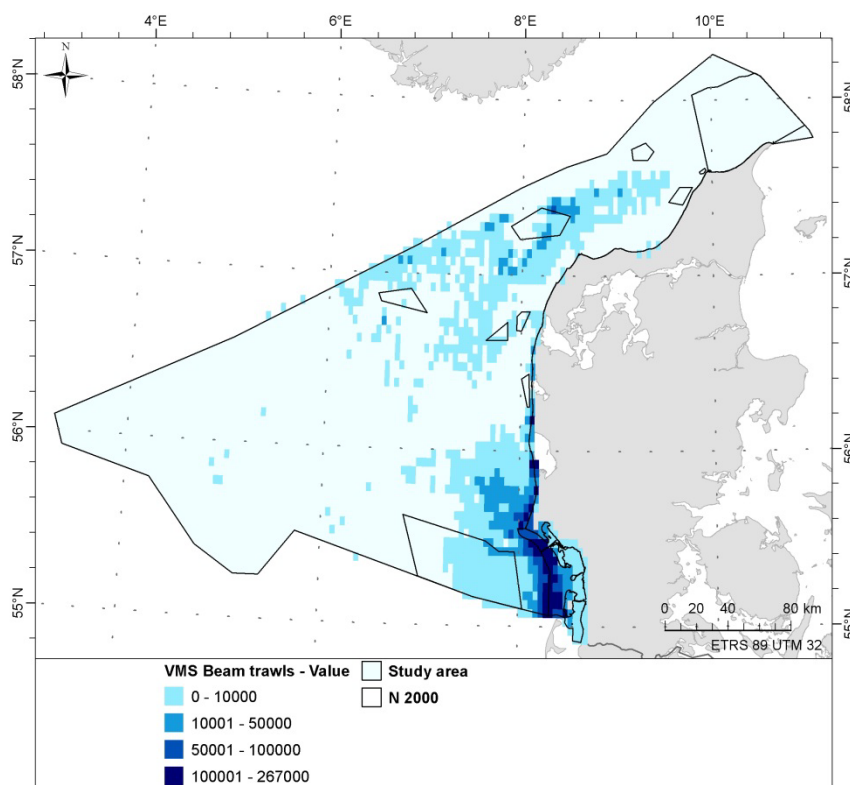


Figure 2 Average annual value (Euro) of landings from the Danish beam trawl fishery.

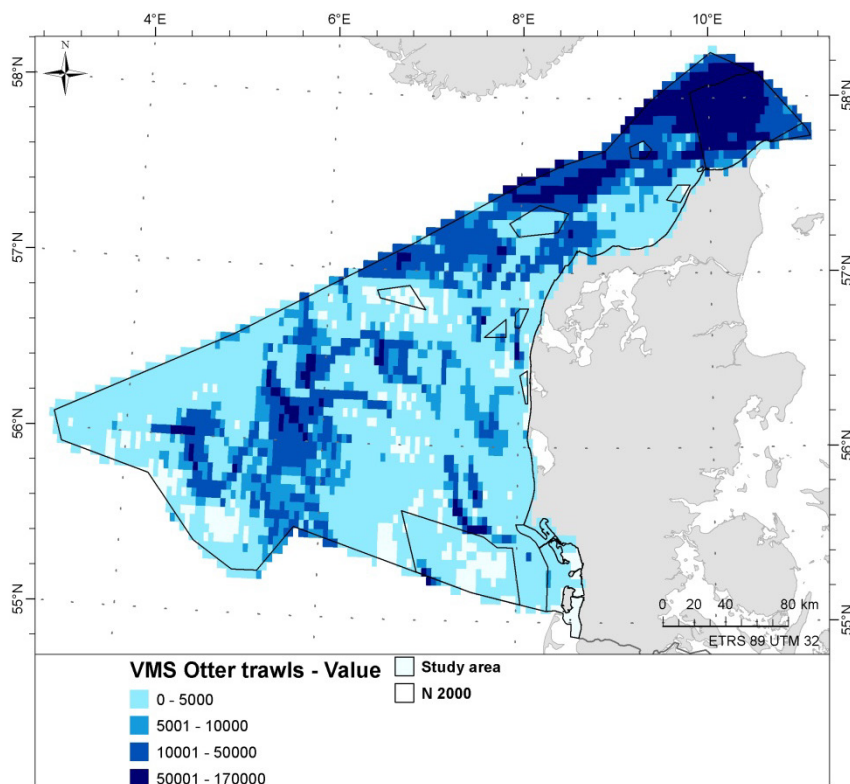


Figure 3 Average annual value (Euro, 2012-2016) of landings from the Danish Otter Trawl fishery.

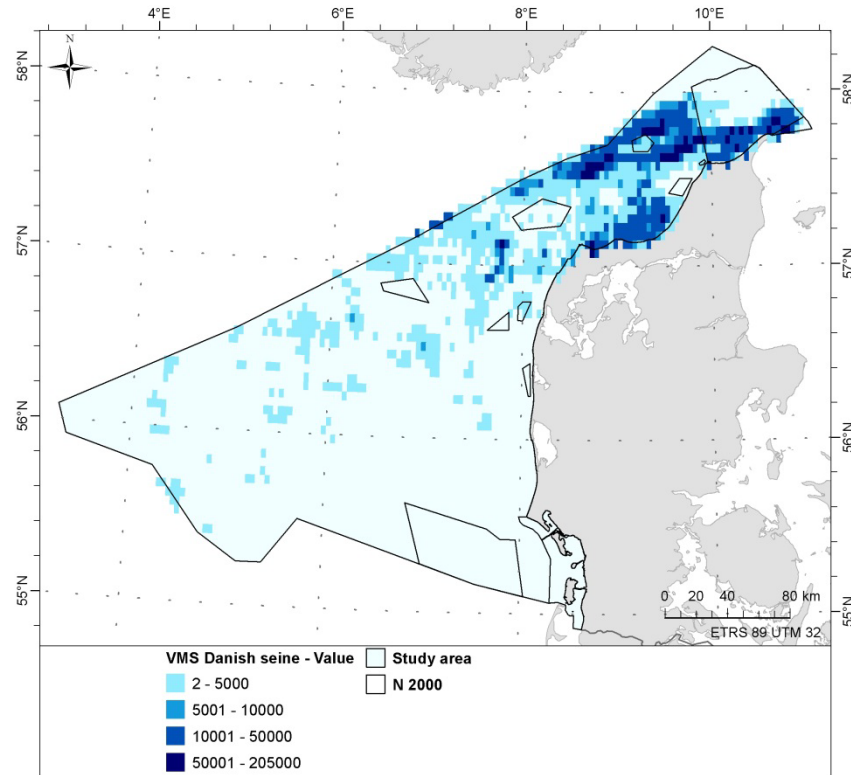


Figure 4 Average annual value (Euro, 2012-2016) of landings from the Dansih Danish Seine Fishery.

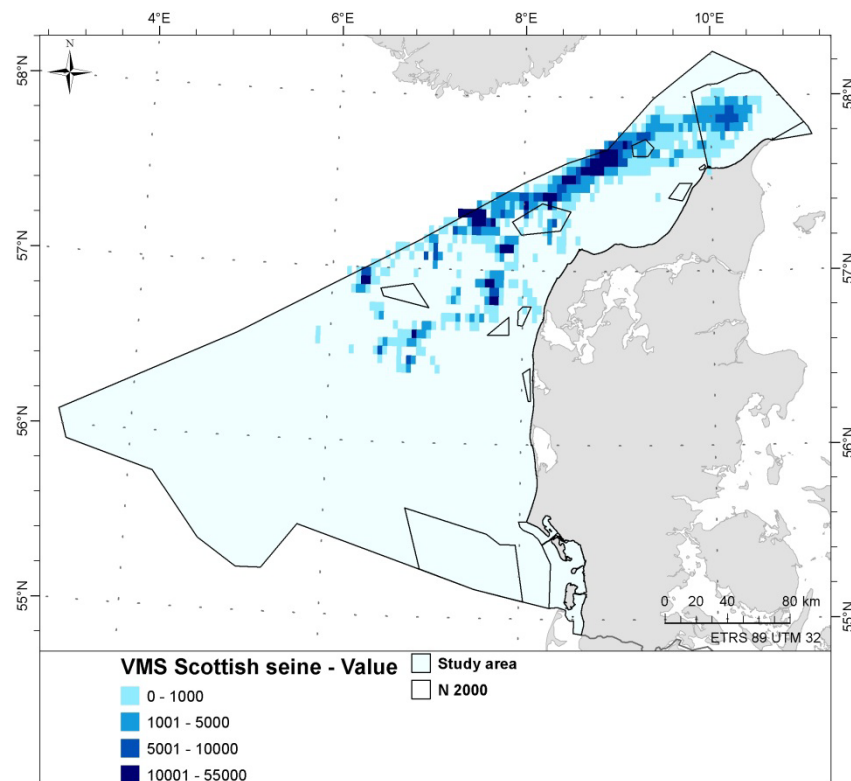


Figure 5 Average annual value (Euro, 2012-2016) of landings from the Danish Scottish Seine fishery.

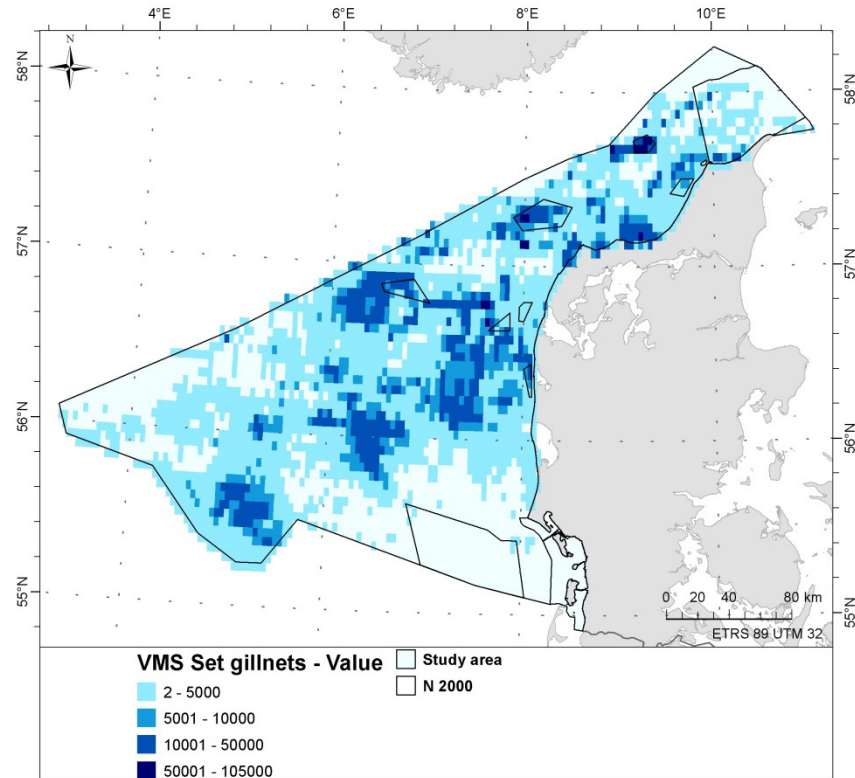


Figure 6 Average annual value (Euro, 2012-2016) of landings from the Danish Set Gillnet fishery.

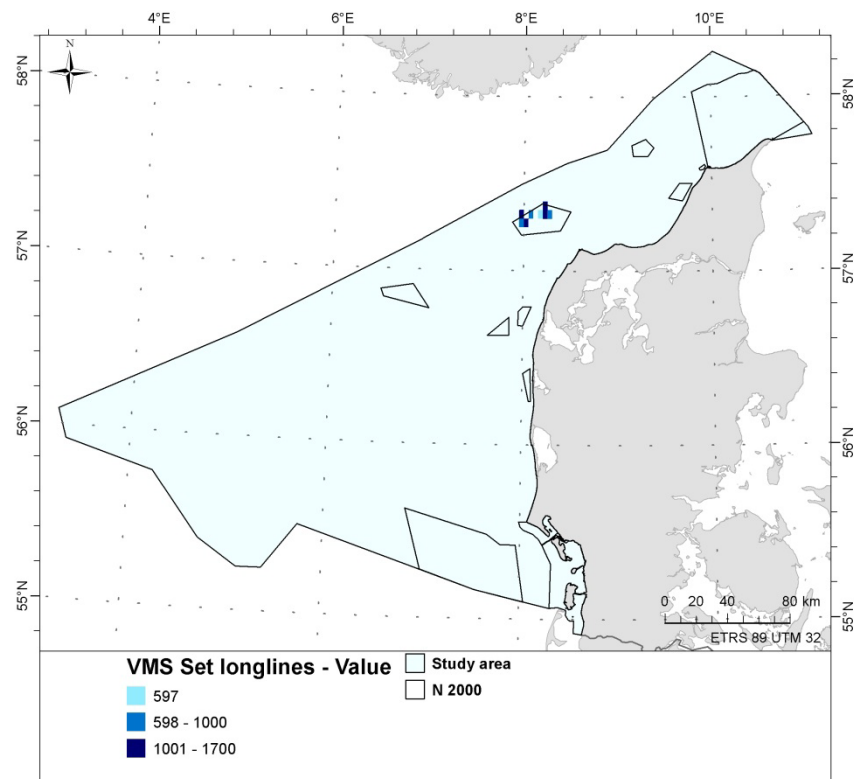


Figure 7 Average annual value (Euro, 2012-2016) of landings from the Danish Set longlines fishery.

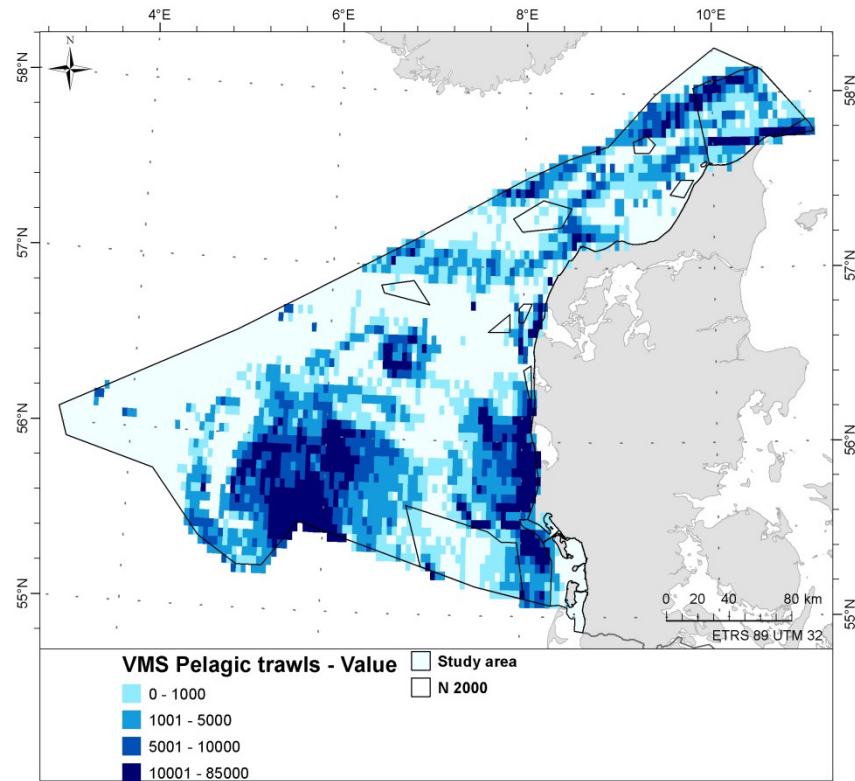


Figure 8 Average annual value (Euro, 2012-2016) of landings from the Danish Pelagic Trawl fishery.

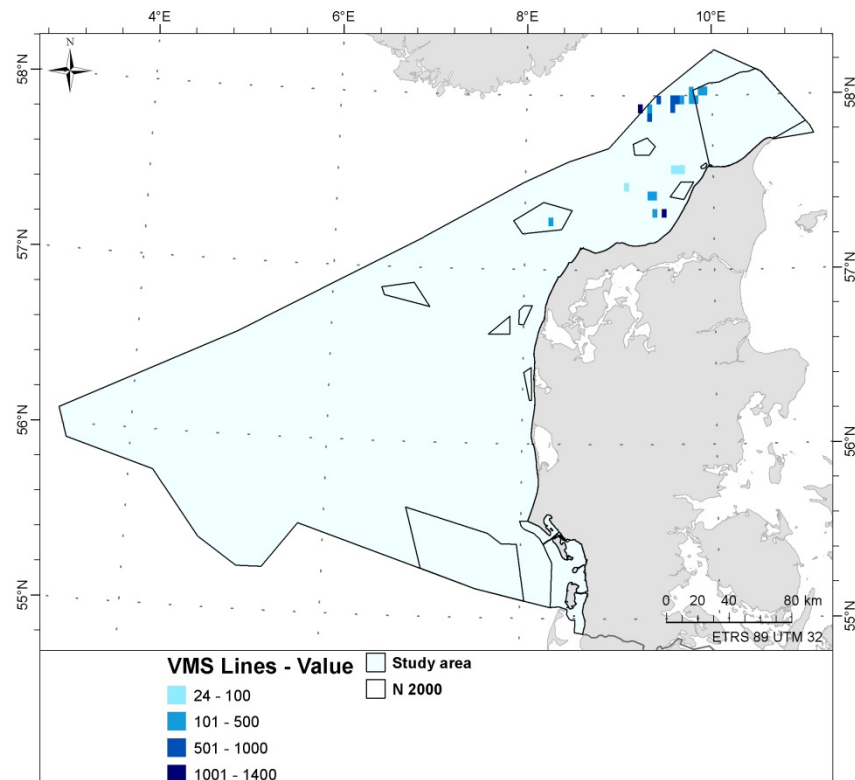


Figure 9 Average annual value (Euro, 2012- 2016) of the landing from the Danish Line fishery.

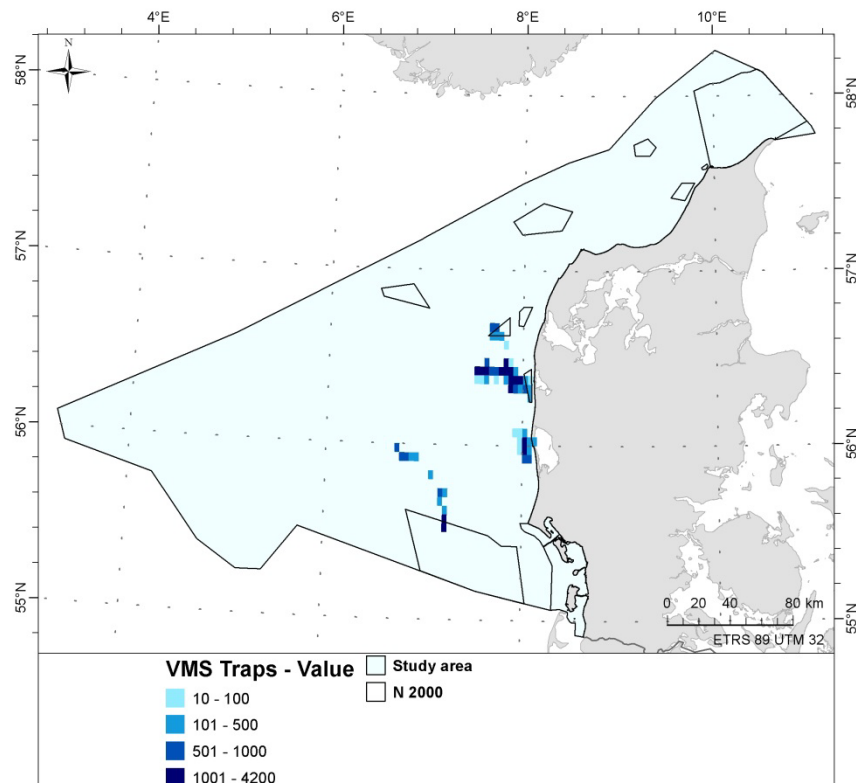


Figure 10 Average annual value (Euro, 2012-2016) of landings from the Danish Trap fishery.

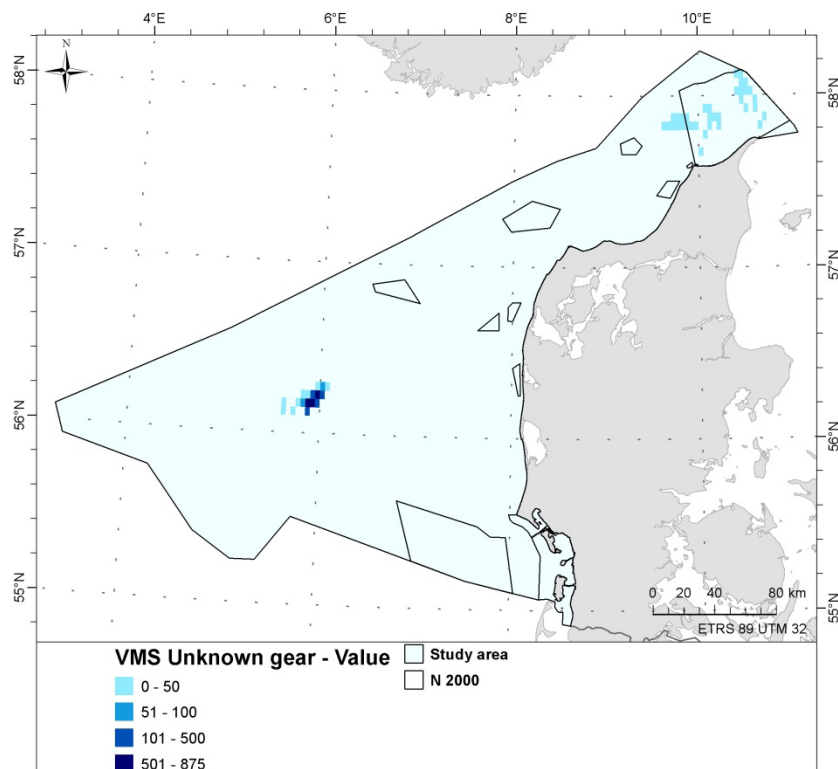


Figure 11 Average annual value (Euro, 2012-2016) of landings from other Danish fisheries.

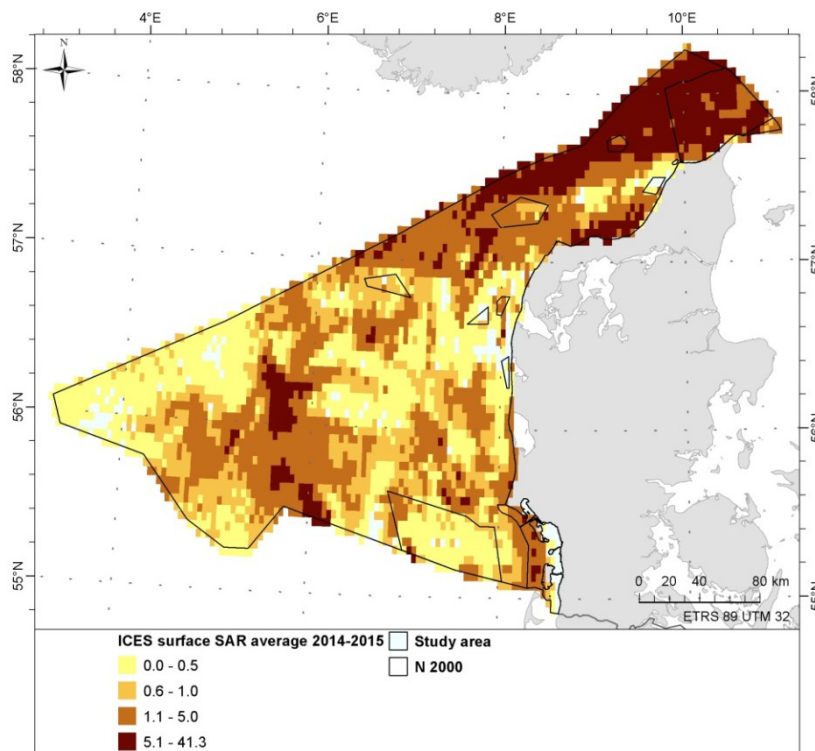


Figure 12 Surface Abrasion Ratios (km² swept per km²) caused by mobile bottom contacting gears, 2014-2015.

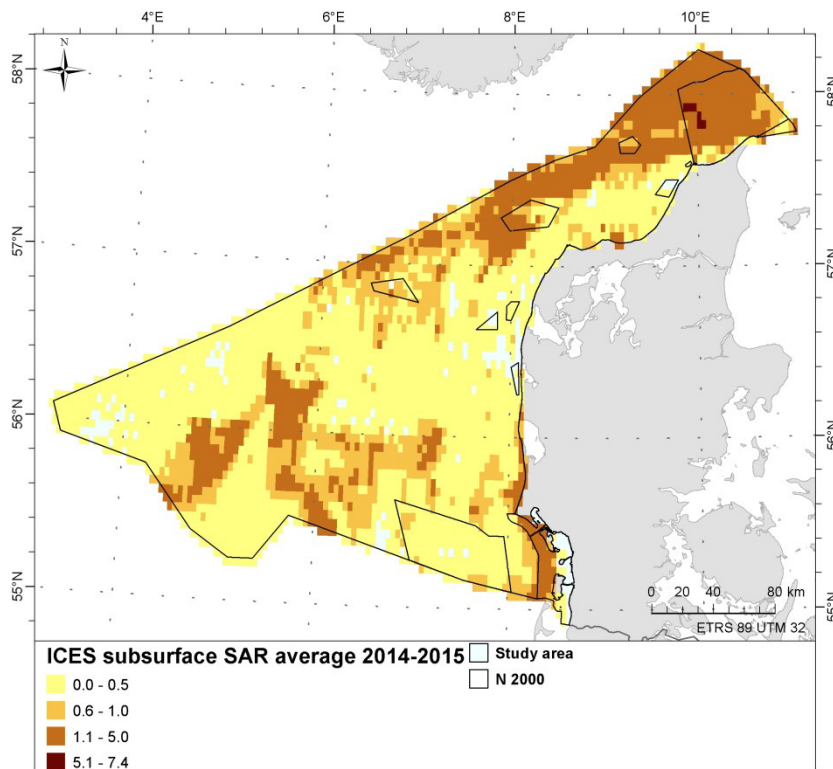


Figure 13 Sub-surface Abrasion Ratios (km² swept per km²) caused by mobile bottom contacting gears, 2014-2015.

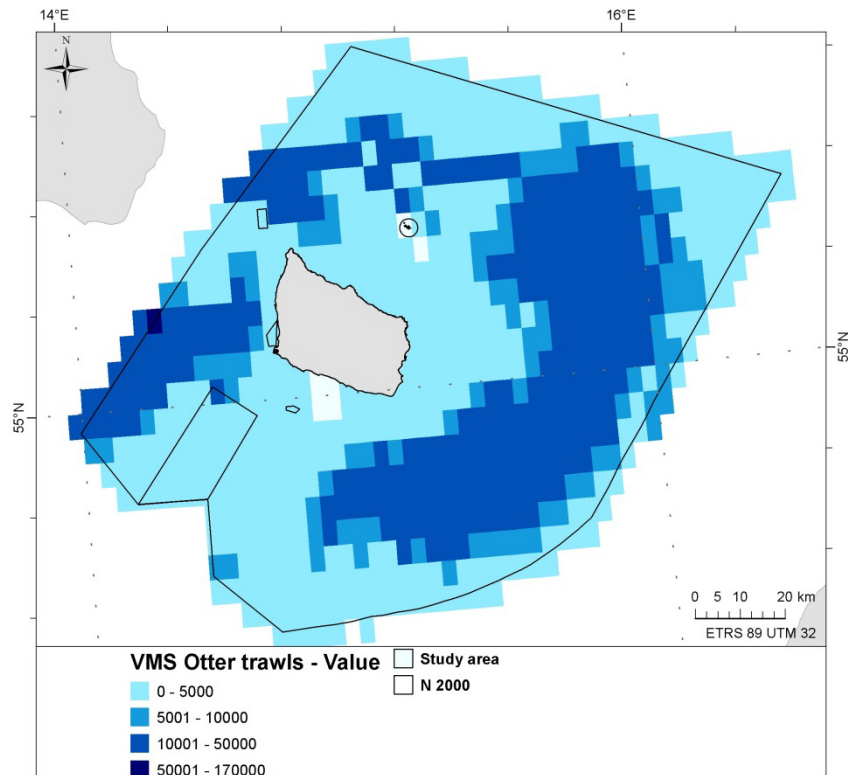


Figure 14 Average annual value (Euro, 2012-2016) of landings from the Danish Otter trawl fishery.

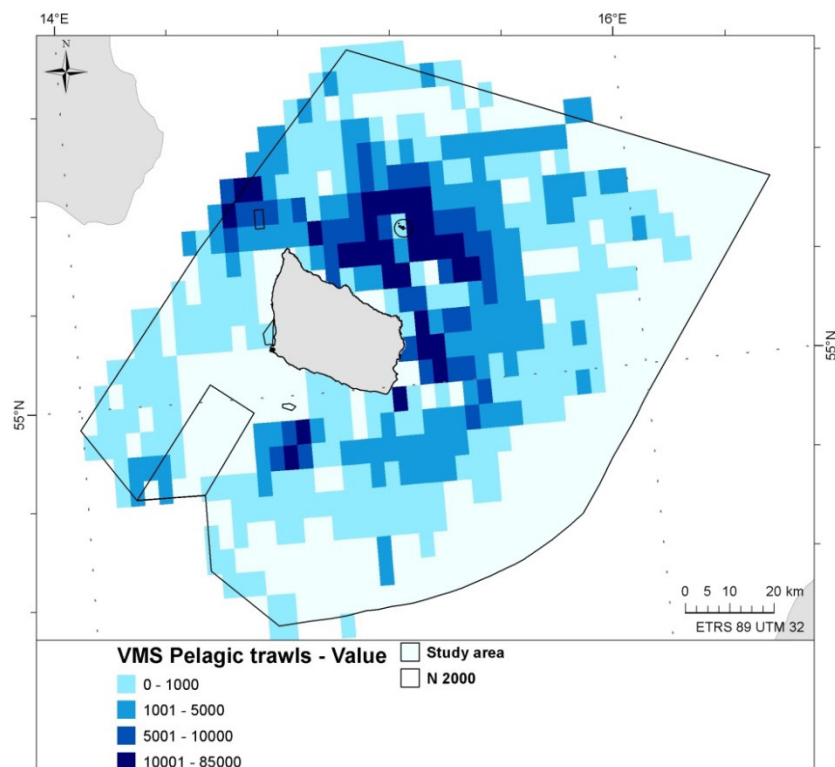


Figure 15 Average annual value (Euro, 2012-2016) of landings from the Danish Pelagic Trawl fishery.

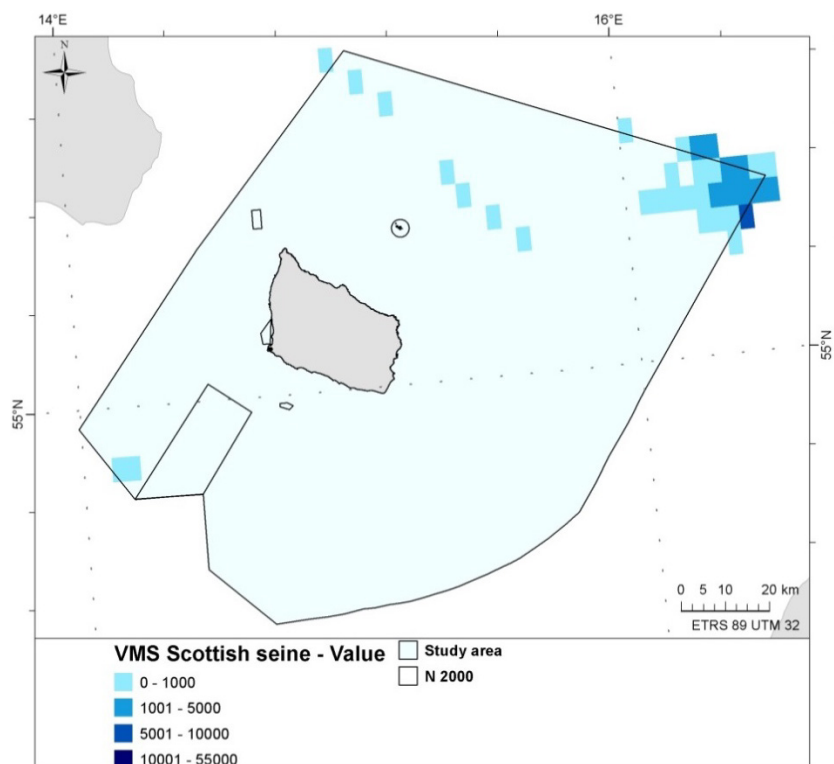


Figure 16 Average annual value (Euro, 2012-2016) from the Danish Scottish Seine fishery.

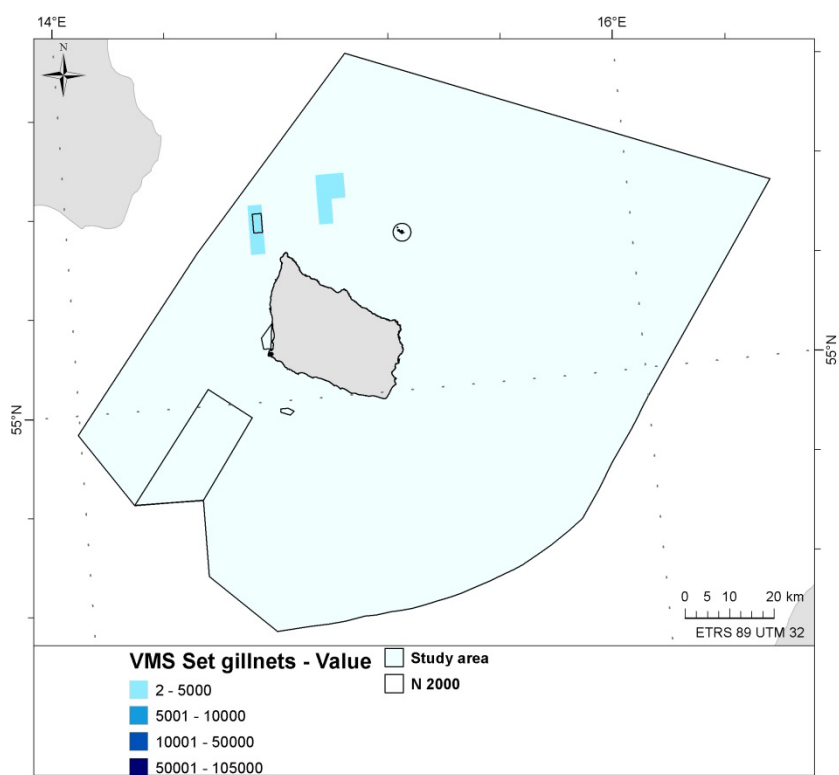


Figure 17 Average annual value (Euro, 2012-2016) of landings from the Danish Set Gillnet fishery.

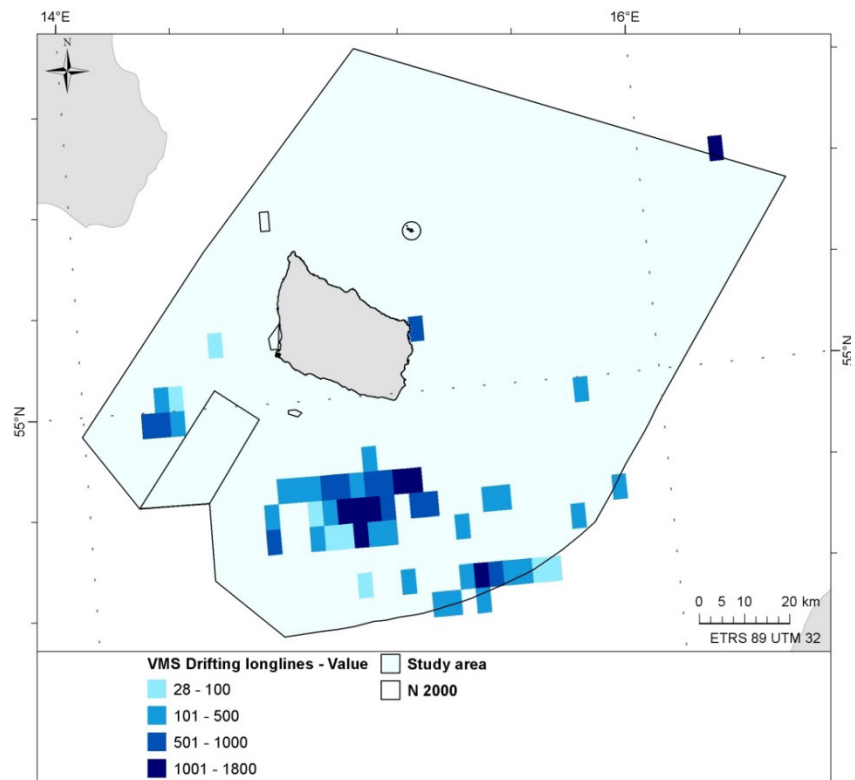


Figure 18 Average annual value (Euro, 2012-2016) of landings from the Danish Drifting Longline fishery.

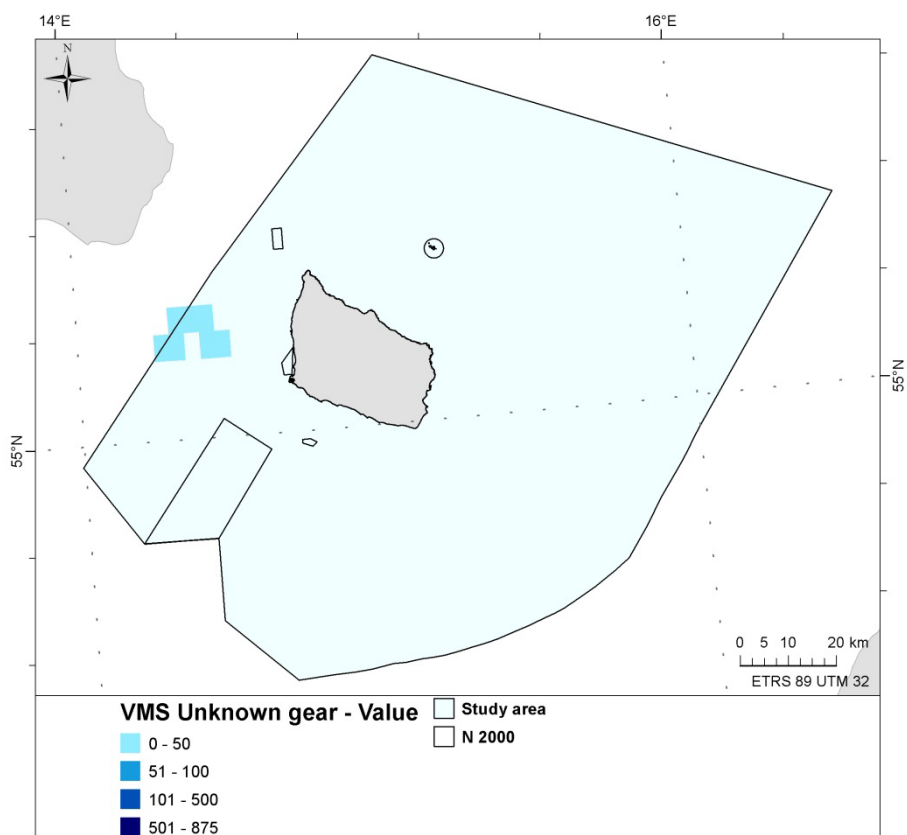


Figure 19 Average annual value (Euro, 2012-2016) of landings from Other Danish Gears.

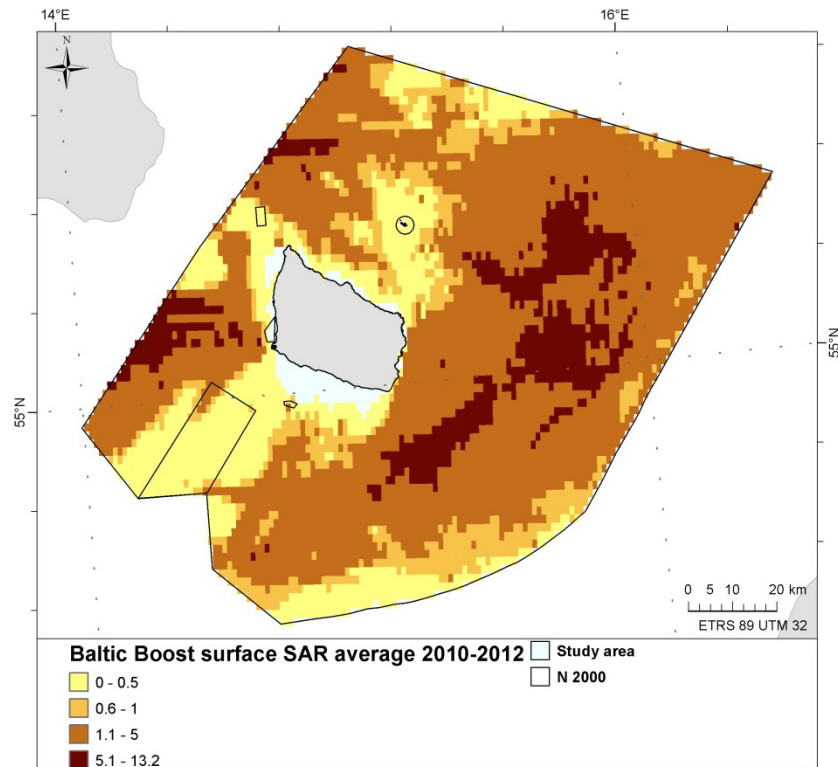


Figure 20 Surface Abrasion Ratios (km^2 swept per km^2) caused by mobile bottom contacting gears, 2014-2015.

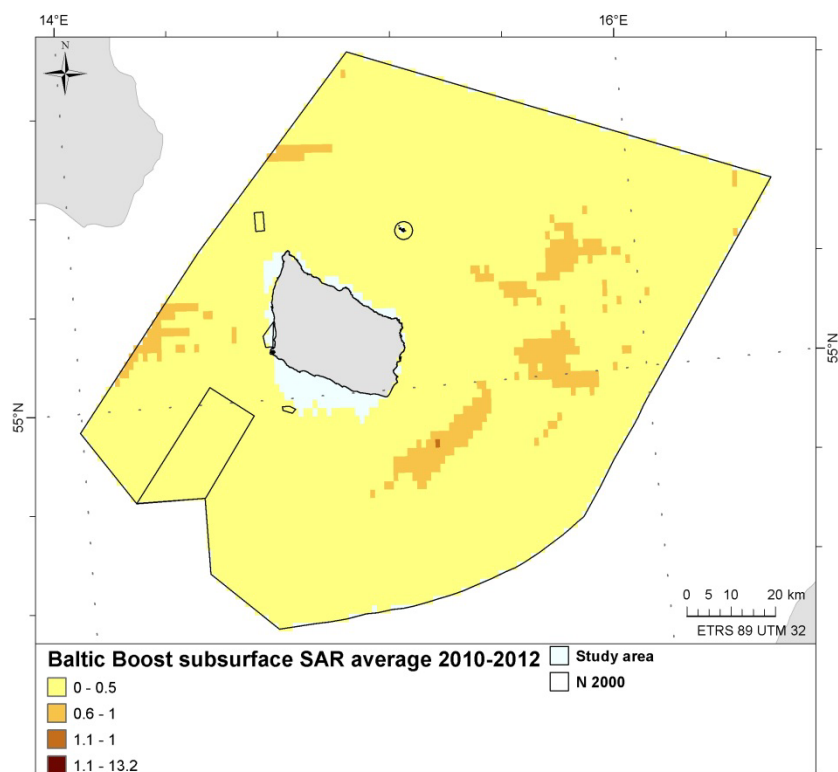


Figure 21 Sub-surface Abrasion Ratios (km^2 swept per km^2) caused by mobile bottom contacting gears, 2014-2015.

6.3 Aggregates: distribution, classification and evaluation

Marine aggregates vary widely in type and environment in which they occur. In this context, aggregates are defined as marine sand, gravel and pebbles. The aggregates are principally extracted by dredging and used in construction, laying roads, coastal protection and beach replenishment. The economic value of the marine aggregates, in general, is variable due to many factors such as resource quality, accessibility, water depth, distance to harbour, and market conditions. The economic interest fluctuates with trends in usage, availability and markets, but the interest, in general, is growing as the pressure on terrestrial resources increases.

The marine aggregates in the North Sea (Figure 22) and the central Baltic Sea around Bornholm (Figure 23) have been mapped during the last decades. The classification of the resource areas basically distinguishes between current production areas according to licensing, and resource areas, which potentially can be exploited in the future.

In this report we consider three different categories of values. The first category “Currently active production areas” is defined by the presence of actual production based on licenses issued and total production statistics from 2015-2017 based on the actual production volumes reported to Miljøstyrelsen (<http://mst.dk/erhverv/raastoffer/statistik-om-raastoffer/>). These areas are evaluated as high value areas.

The “Current production areas” include:

1. Common areas where the companies holding a license are currently dredging.
2. Dredging areas within the reservation areas where dredging licences can be issued upon request for coastal replenishment or development projects.
3. Auction areas where exclusive dredging licenses have been issued.

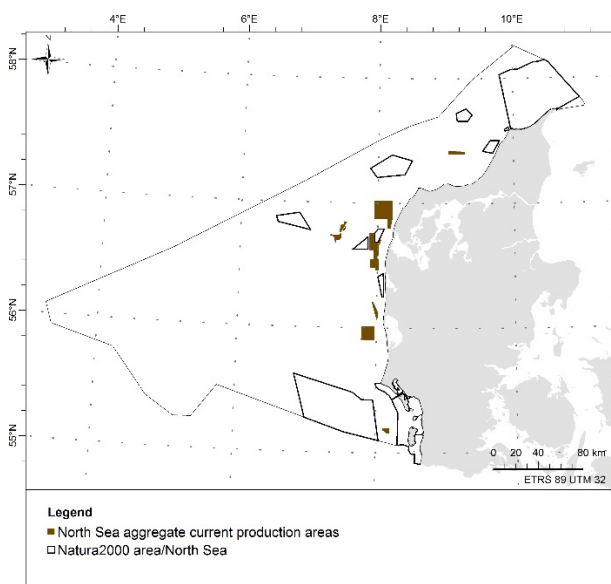


Figure 22 Current aggregate production areas in the North Sea. Please refer to text for details.

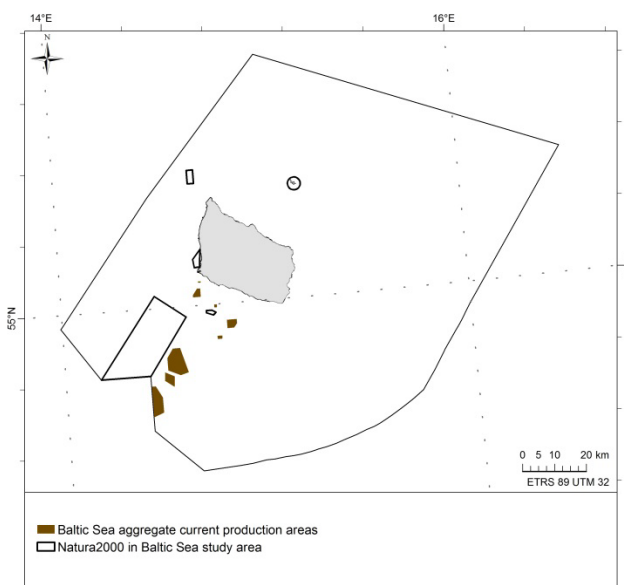


Figure 23 Current aggregate production areas in the Baltic Sea. Please refer to text for details.

The second category “Currently inactive common license areas” includes common areas not currently being exploited according to the reported statistics (see above). However, they are designated as licensed resource areas where dredging permits can be issued according to the Ministerial order. Their status is in this context evaluated as medium value areas (Figure 24 and Figure 25), but they could change to high value areas when dredging permits have been issued and exploitation begins. If the holder of the exploitation permit wants to take advantage of the prior dredging permission, these areas will change status to high priority areas.

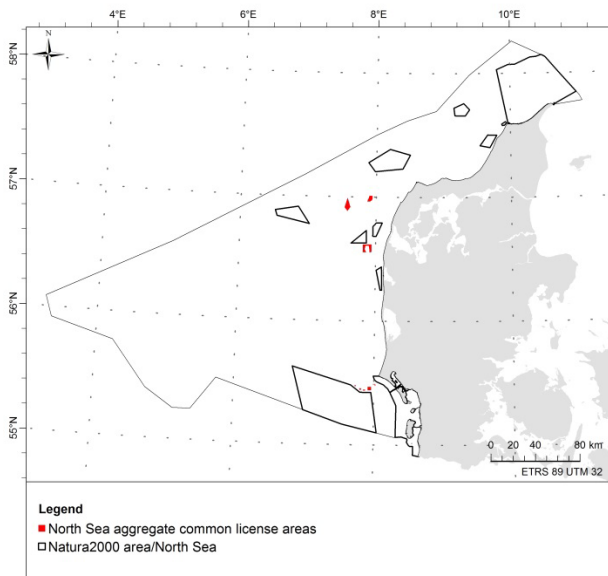


Figure 24 Reserved common license areas in the North Sea.

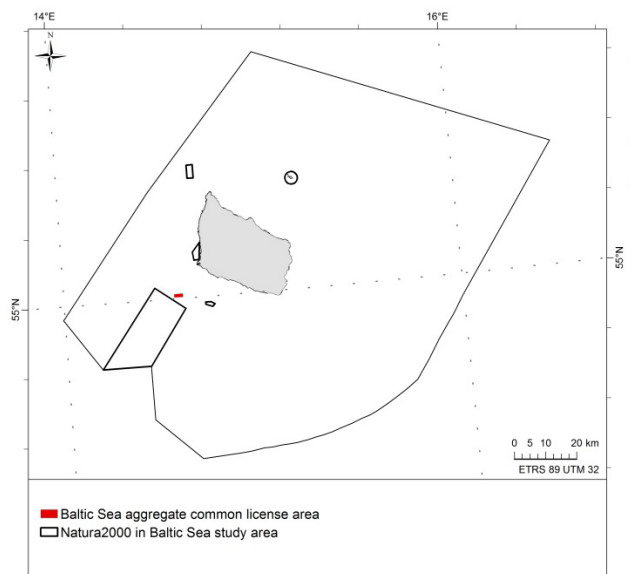


Figure 25 Reserved common license areas in the Baltic Sea.

The third category is named “Potential aggregate areas”. These areas all contain resources, which have been mapped during the last decades. They are part of the Danish marine aggregate planning and serve as areas that may potentially be licensed and used by the aggregate industry. The areas have three levels of confidence, but in this context, they are merged into one category. Their status is evaluated as aggregate reserves, but they are assumed to have the lowest value. Their extent and value may change in the future with better mapping or changes in resource demands (Figure 27 and Figure 27). It is worth mentioning that exploration areas under investigations are not included. .

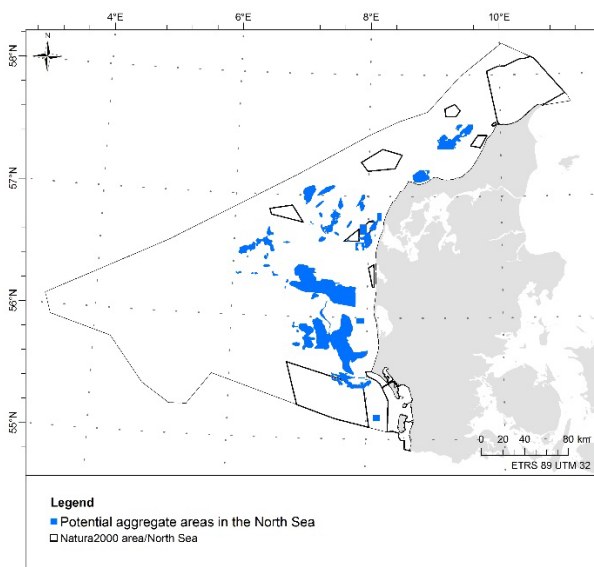


Figure 26 Potential aggregate areas in the North Sea.

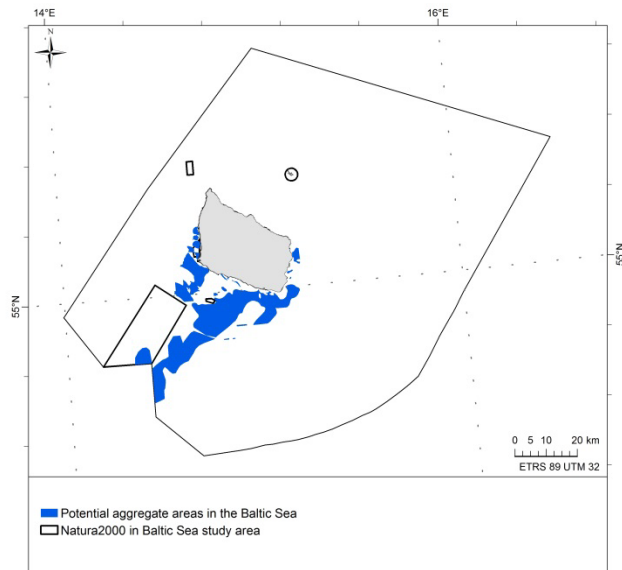


Figure 27 Potential aggregate areas in the Baltic Sea.

6.4 Windfarms

In the North Sea (Figure 28), there are three current windfarms, Horns Reef I, II and III. In addition, two nearshore windfarms are under development, the Vesterhav Syd and Vesterhav Nord. The latter two are planned to be in production no later than 2020. In the Baltic Sea, a similar nearshore windfarm is planned southwest of Bornholm. This windfarm will also be in production by 2020.

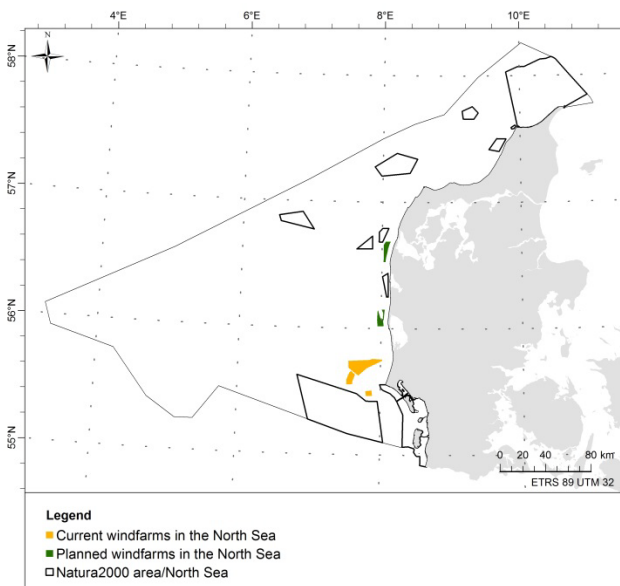


Figure 28 Current & planned windfarms in the North Sea.

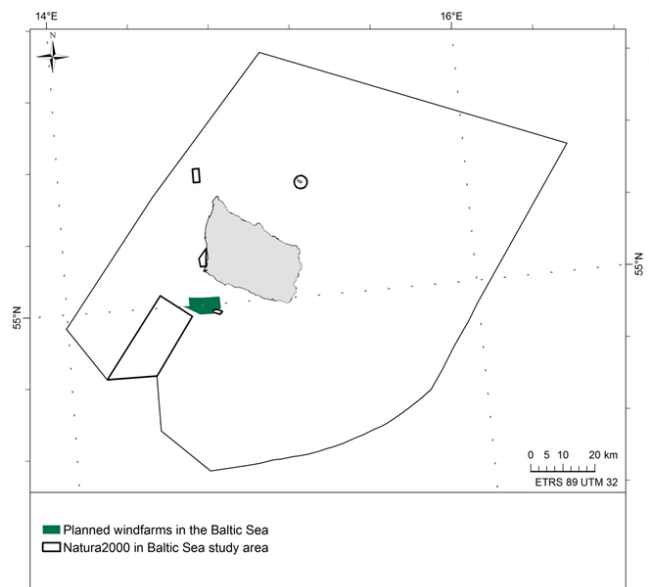


Figure 29 Planned windfarms in the Baltic Sea.

6.5 Oil/gas production

All producing fields in Denmark are located in the North Sea. In total, there are currently 19 fields that have been or are in production. Currently the licence areas cover an area of approximately 60,000 km² equivalents to 10% of the total North Sea area (Figure 30). However, it has been decided in this context to display only the actual offshore installations in operation or under construction, because the actual installation layer is the economic layer that causes pressure and can be used in the model. The other 60,000km² are just administrative layers. The actual installations sum up to 67 points and are shown in Figure 31 together with the layer showing the network of pipelines connecting the oil and gas wells in the North Sea as well as the pipelines transporting oil and gas between the fields and land .

The area around Bornholm is crossed by an existing gas pipeline and a second pipeline is planned parallel to the first one (source: Nord Stream 2017, figure 14). The planned pipeline is not approved yet.

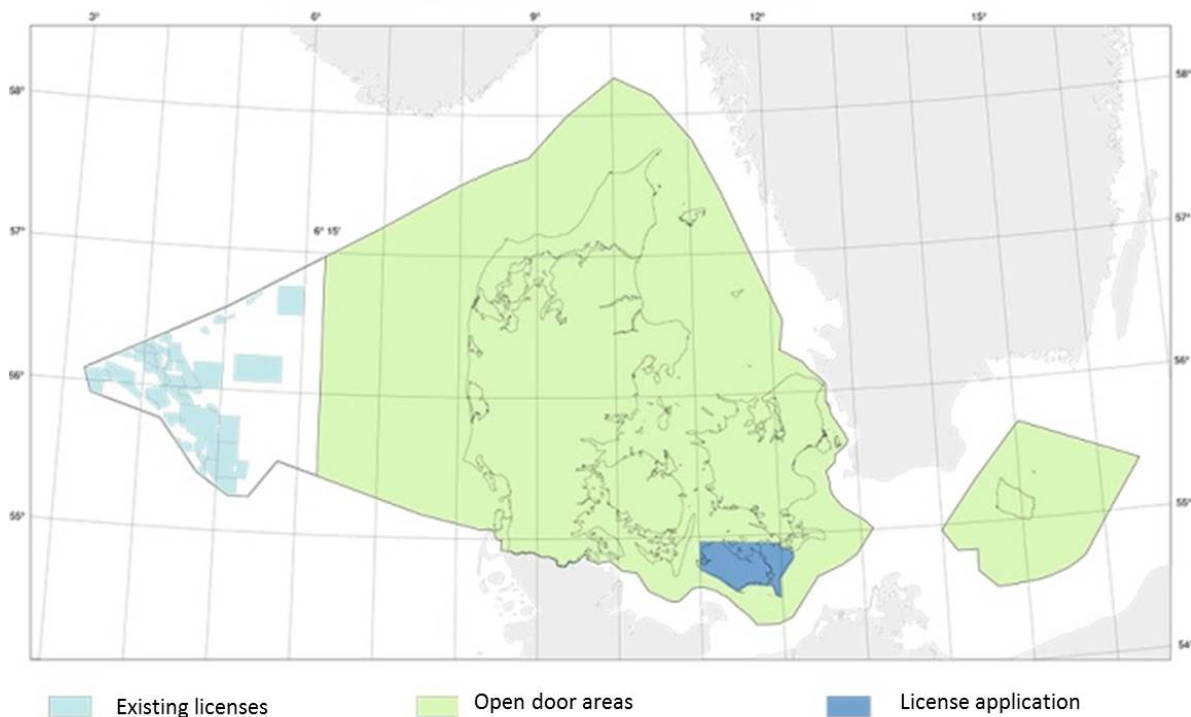


Figure 30 Danish license areas August 2017 (Energistyrelsen).

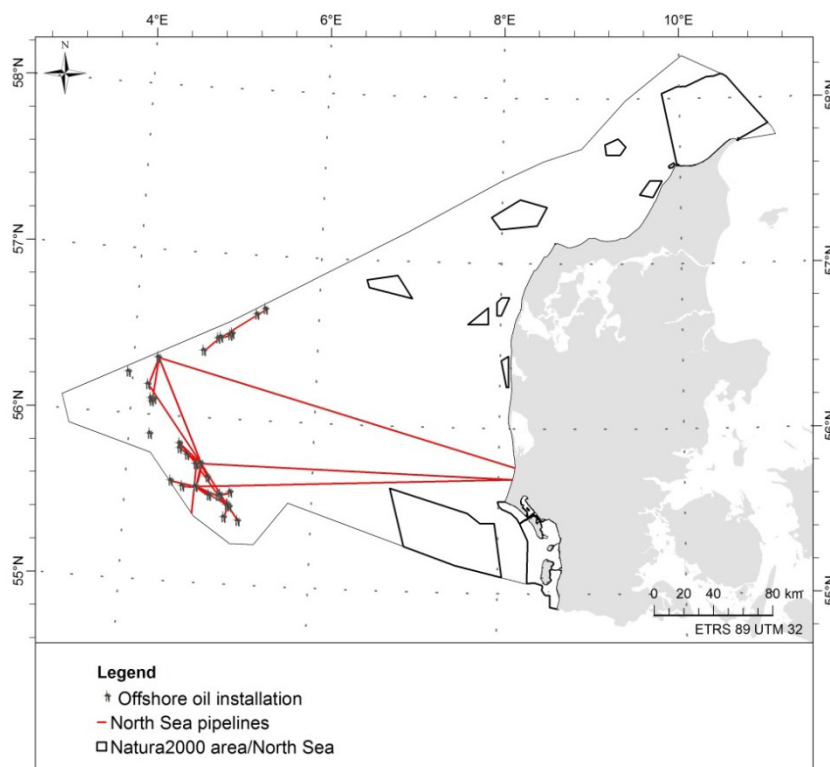


Figure 31 Oil and gas installations and pipelines in the North Sea.

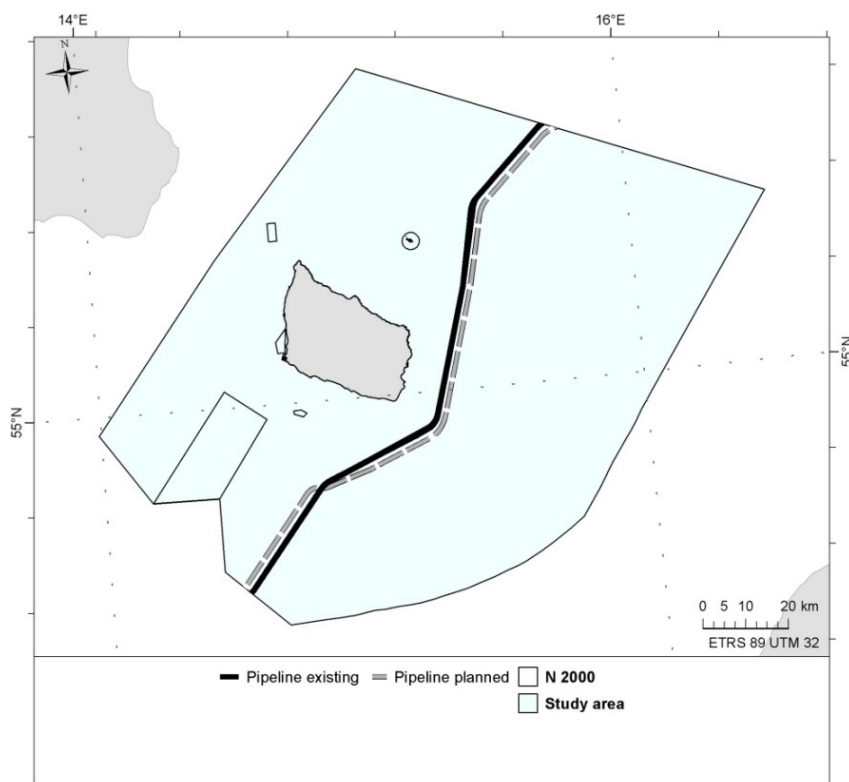


Figure 32 Existing and planned Nord Stream pipeline in the Baltic Sea.

6.6 Wrecks

Based on the database provided by the Ministry of Culture and Places (<http://www.kulturarv.dk/fundogfortidsminder>) the locations of shipwrecks have been mapped. The list contains all registered shipwrecks and parts from shipwrecks.

Ship wrecks are widely distributed in the Baltic (Figure 34), but are more concentrated nearshore and in the northern part of the Danish area in the North Sea (Figure 33) and Skagerrak.

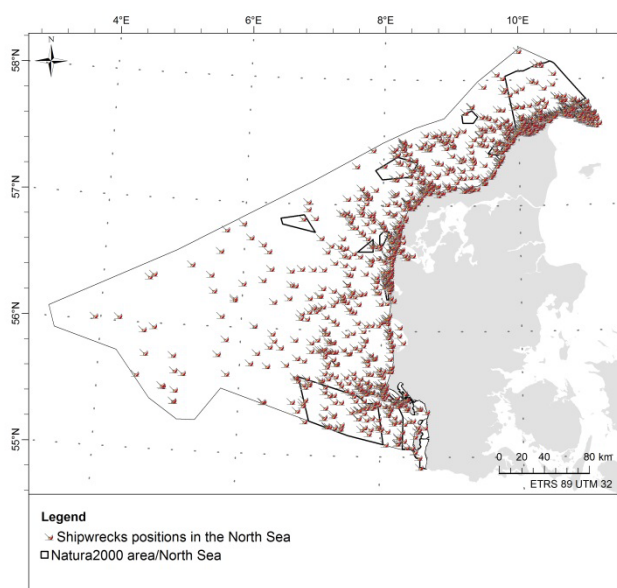


Figure 33 Shipwreck positions in the North Sea.

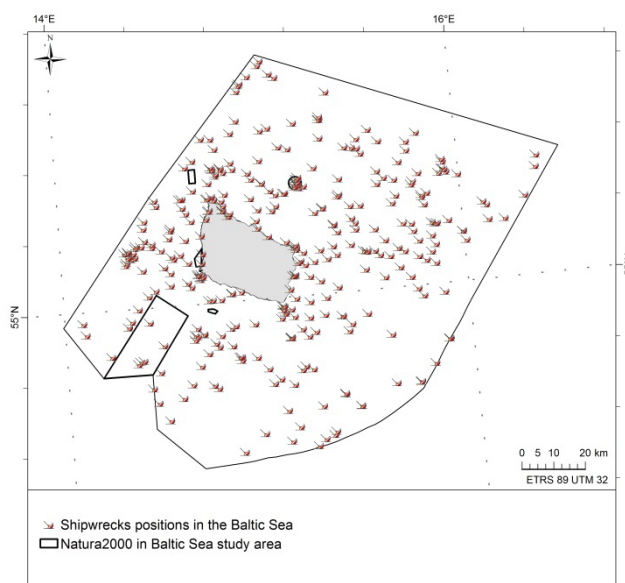


Figure 34 Shipwreck positions in the Baltic Sea.

6.7 Other human factors

Maps of AIS vessel tracking data, cable routes, areas used for military purposes, for dumping of munition during WW2 (Baltic) and the Polish claim (Baltic) are shown in Figure 35 to Figure 43.

The AIS data were obtained from different sources. In the Baltic Sea, HELCOM provides mean densities for all ship types for the years 2011 to 2015. In the North Sea, the data are from year 2009 and were taken from the HARMONY project (Andersen et al. 2013), Figure 35 and Figure 36.

For the Baltic Sea, HELCOM also provides information about dumped chemical munitions from World War 2. In figure 23, the official area for dumping plus an outline within which munition has been encountered is shown. It is well known that much munition already was dumped en route to the dumping site, so munition may also be found outside of this area, Figure 37.

Poland is objecting to the current EEZ border and is claiming an area up to the territorial border. The Polish claim is shown in figure 38.

Aggregate dump sites are shown in Figure 39, these data were not used in the final model. The dump areas are mainly located outside the study areas in the North Sea; only one exists in the area around Bornholm (<http://miljoegis.mim.dk/cbkort?profile=klapsager>).

The data for cables are based on several sources. Most of the data are based on information provided by the Danish Cable Protection Committee, but this dataset only contains information about the cable from

Committee members. Where possible the cable data were therefore supplemented with information from the nautical chart. (Mohn et al. 2015), Figure 40 and Figure 41.

The information about military areas were taken from the SYMBIOSE project and updated with information for 2017 from the nautical charts and the Danish Maritime Authority (<http://nautiskinformation.soefartsstyrelsen.dk/#/messages/map>, 2017/07/27, Mohn et al. 2015), Figure 42 and Figure 43.

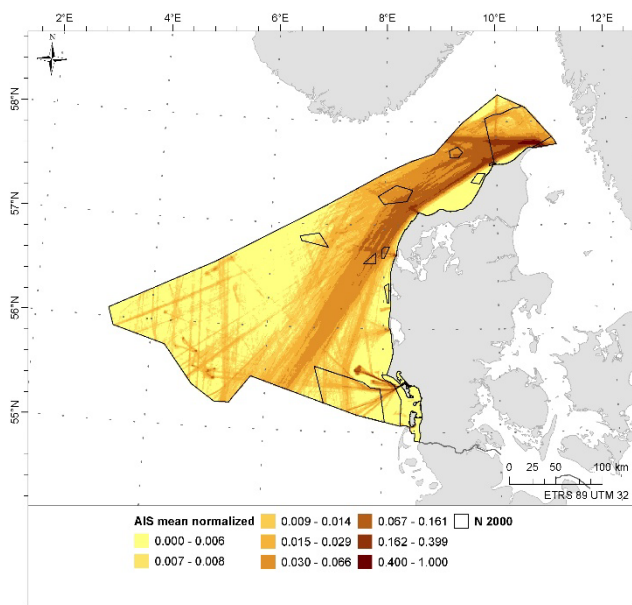


Figure 35 Shipping intensity during 2009 (source: HARMONY Andersen et al. 2012).

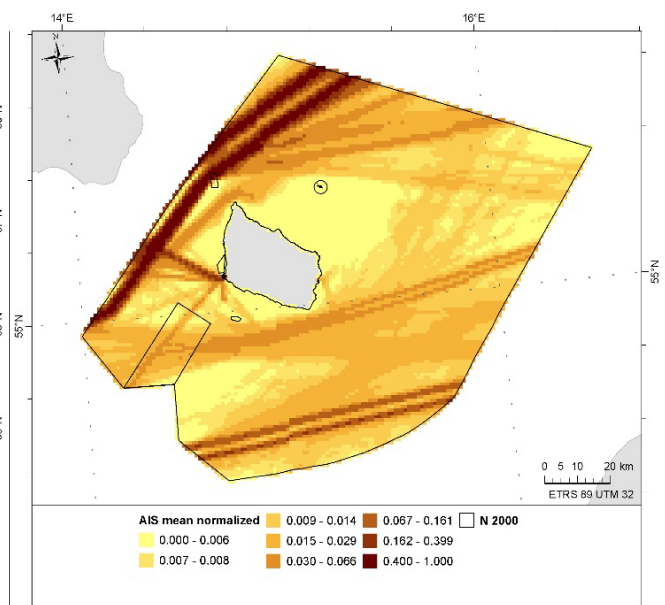


Figure 36 AIS sum of ships in 1km grid cells during the years 2011-2015 (source: HELCOM).

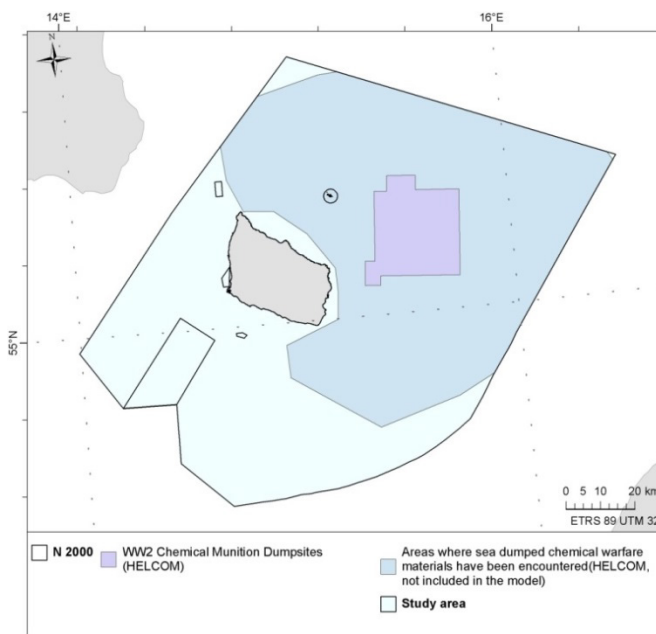


Figure 37 Ammunition dumping site in the Baltic Sea.

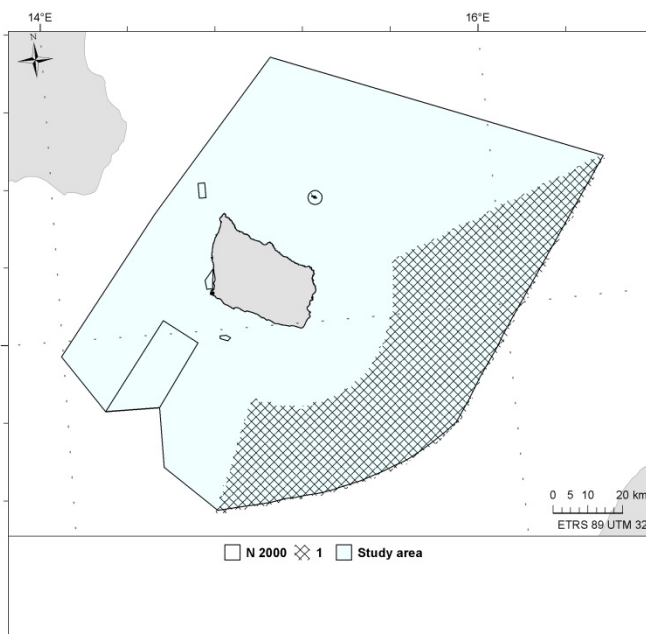


Figure 38 Polish claim in the Baltic Sea.

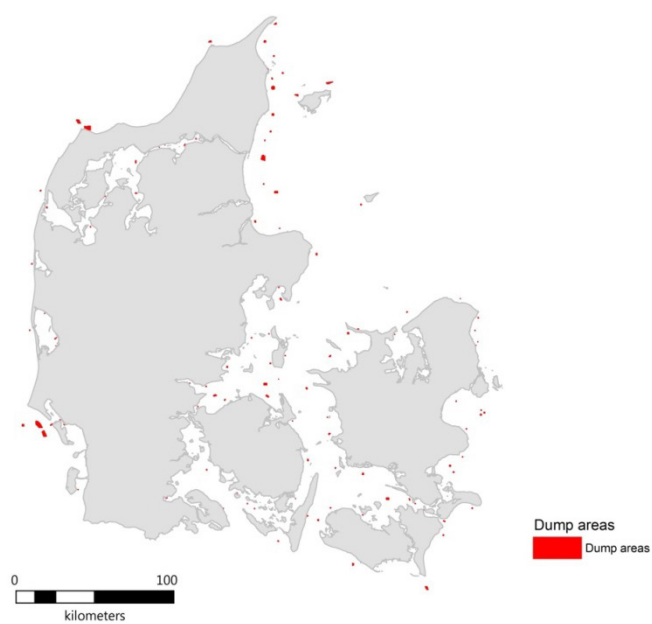


Figure 39 Dumping sites in Danish waters. Source Miljø-og Fødevareministeriets portal.

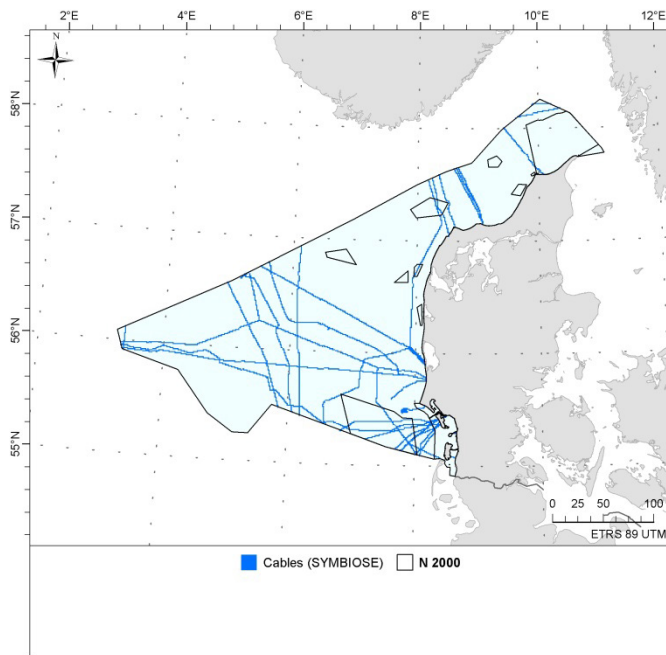


Figure 40 Cable routes in the North Sea.

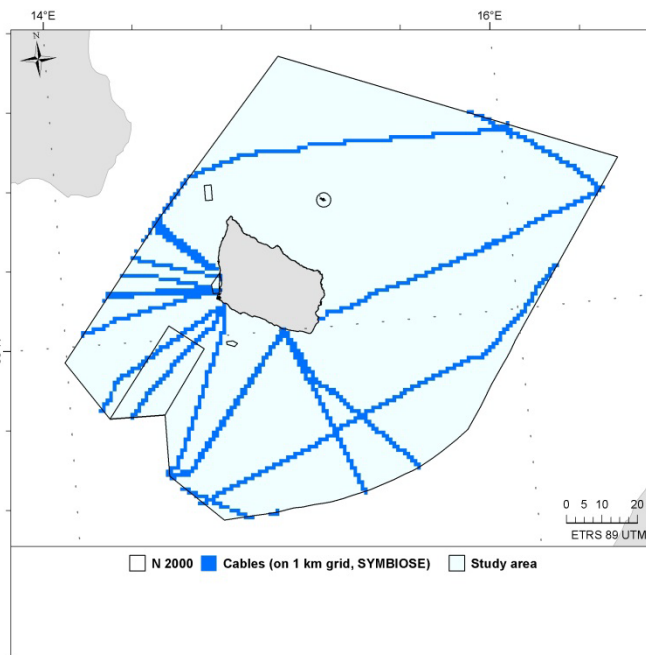


Figure 41 Cable routes in the Baltic Sea.

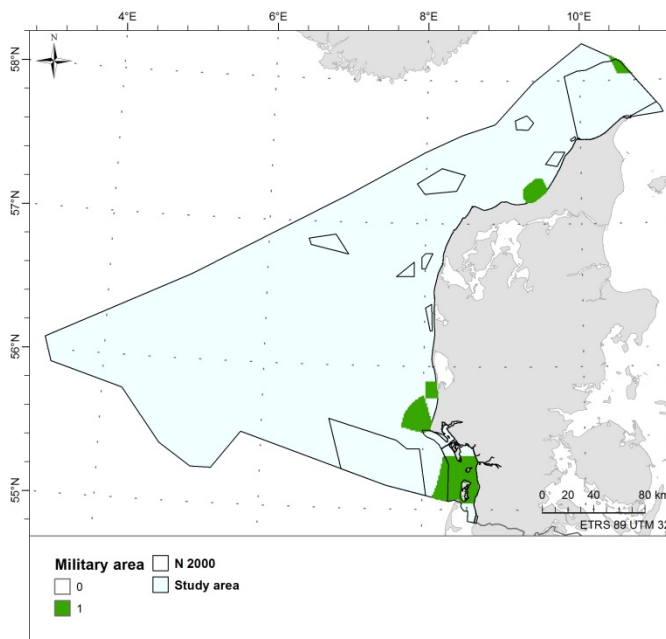


Figure 42 Military areas in the North Sea.



Figure 43 Military areas in the Baltic Sea.

7. Connectivity

Many marine animals are able to swim over large distances to locate suitable spawning habitats and feeding grounds, and there are generally fewer physical barriers to dispersal in the sea than on land. However, sessile animals with passively drifting life stages such as pelagic eggs and larvae face a particular challenge.

Marine sessile benthic species are often characterized by a series of local populations linked by the exchange of passively drifting spores or larvae. The connectivity between these populations is the basis for their existence and enables them to re-establish demographic structure and genetic diversity after disturbance. This means that connectivity is a key factor to consider in the design of marine protected areas. Other marine species also disperse by means of passively drifting pelagic eggs and larvae (e.g. fish, jellyfish). For all these species the connectivity between spawning locations and suitable nursery grounds depends on the passive transport offered by currents. Connectivity in the sea is therefore not only a question of geographical distance or size of adult home range (which is often unknown), but also a question of whether larvae produced in a given area are able to drift with the currents to a suitable area where they can settle, survive and grow.

In this section we use a hydrographic model of larval transport, IBMlib, to predict where the currents will carry the eggs and larvae produced at different locations in the two zones. This allows us to estimate the contribution of each donor location to the areas where the larvae or juveniles may settle. We define connectivity as the 'sourciness' of a particular area, a value that expresses the likelihood that the location considered will produce larvae that settle on the same habitat and in the same zone as on the location where it was produced. We use the connectivity thus estimated to rank the locations. If all larvae produced on a given location and habitat within a zone ends up settling in the same zone and habitat, that particular location is more valuable than locations producing larvae that will be swept outside the zone or to another habitat. Repeating this procedure for all locations within the zone generates a map of the 'sourciness' of each location. We use these maps to reflect connectivity.

Together with the maps of ecological features presented in the previous chapters the connectivity maps are used to reflect the ecological quality of different locations, which is the input required for the spatial planning tools presented in the following chapters.

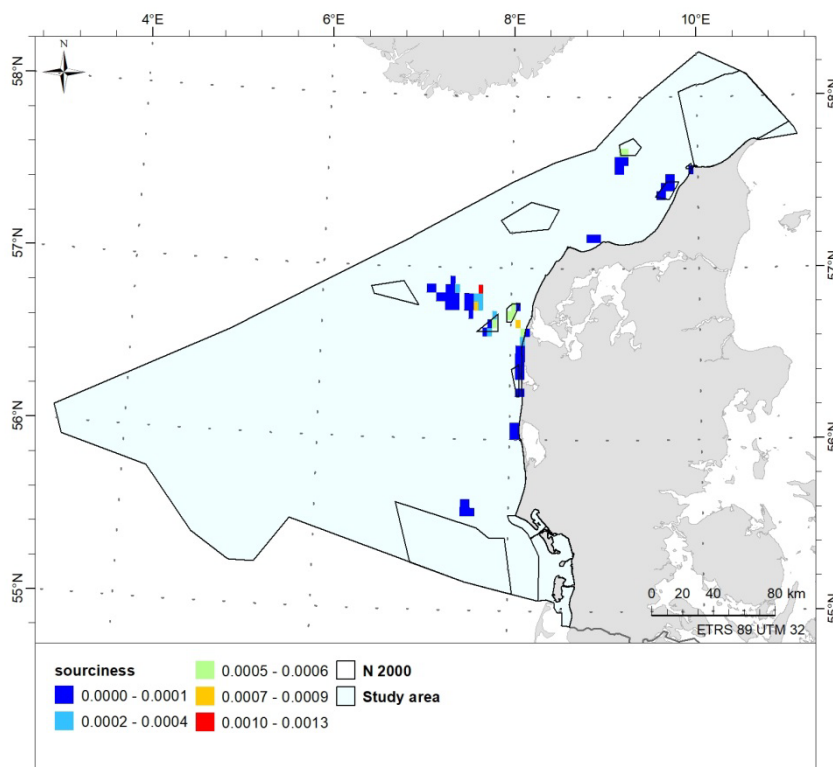
The IBMlib model used to simulate larval drift is presented in Annex 12-1 together with a more precise description of the derivation of the 'sourciness' maps. In the following we present the resulting maps for two different larval release months (March and June), four different habitat types (two hard and two soft bottom habitats, two different larval transport durations (15 days and 45 days) and two different larval behaviour patterns (passively drifting in the entire water column versus being restricted to the layer above the thermocline) . We do this to cover organisms with different reproductive seasons, habitats, transport durations and larval behaviours.

7.1 North Sea

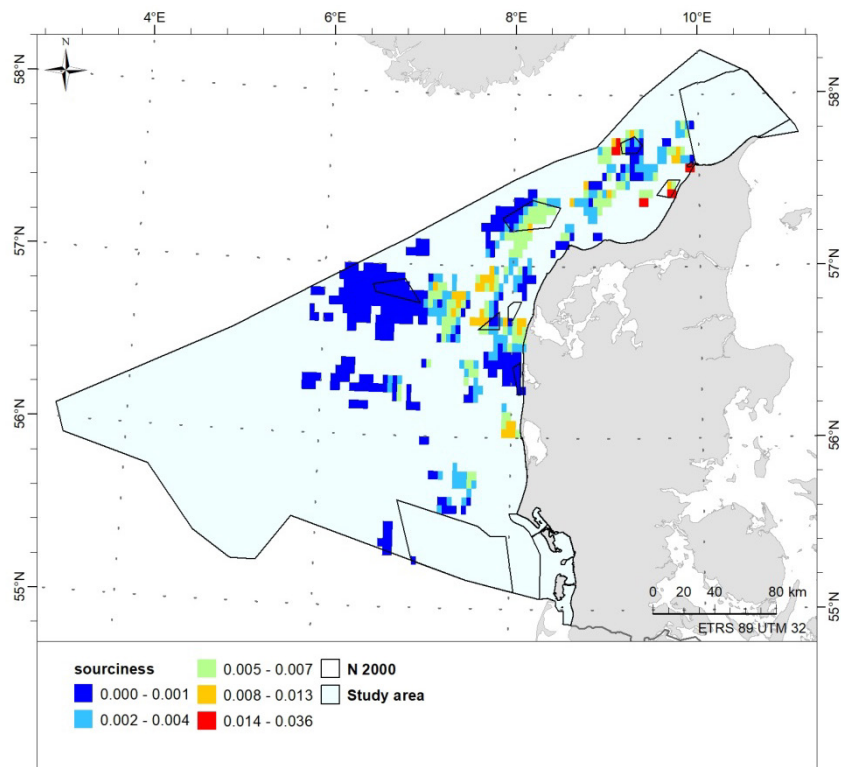
The results of using IBMlib to model the 'sourciness' of each location in the North Sea and Skagerrak zone are shown in Figure 44 to Figure 46. These figures are meant to illustrate the effect of releasing larvae in the four different habitats (Figure 44), and the effect of different release periods, transport durations and larval behaviour for larvae produced in hard bottom areas (Figure 45) and shallow <50m soft bottom areas (Figure 46), respectively. Note that the 'sourciness' scale changes from map to map. The results obviously depend a lot on the traits of the larvae, but the general picture emerging is that hard bottoms are able to repopulate in

March, but less so in June, that deep soft bottoms (>50m) seems well connected, and that shallow bottoms (<50m) along the coast of Jutland and in the most western part of the zone have a high 'sourciness' in March, while in June 'sourciness' is high along in the south and south-western part of the area and in the most western part. Although the larval release month, transport durations, and larval behaviours apparently matters a lot these results appear to reflect the impact of the tidal node (an amphidromic point, where tidal currents are low) situated in the central North Sea near to the western-most part of the zone, and the importance of the general south to north movement of water along the coast of Jutland caused by the anti-clockwise general current pattern.

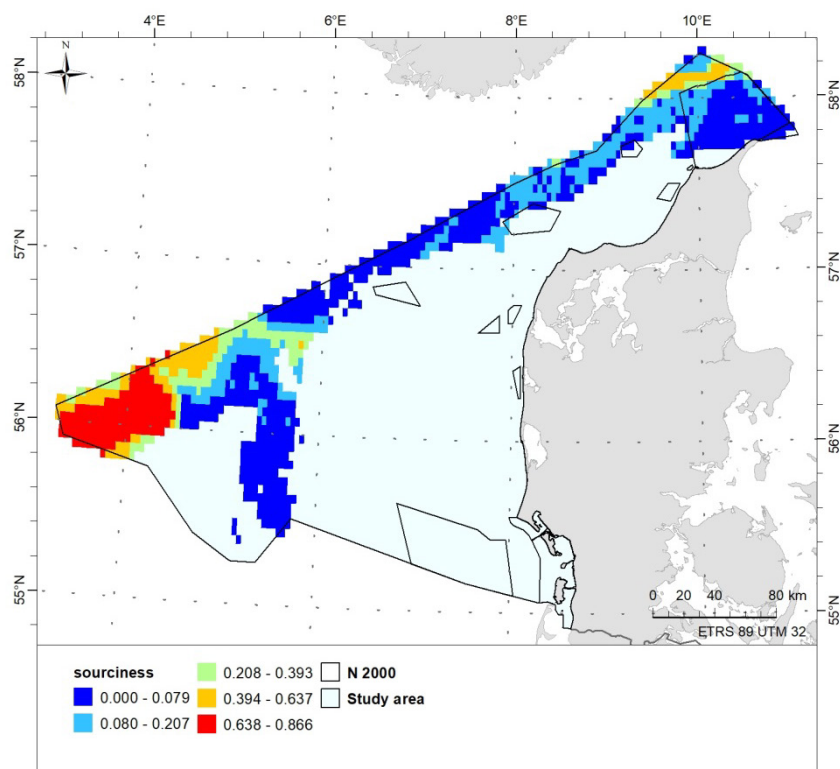
In the following 4 maps in Figure 44, the North Sea connectivity is simulated (from top and down): a) hard bottom (brown algae), b) hard bottom (*Flustra*), c) soft bottom deeper than 50m and d) soft bottom shallower than 50m.



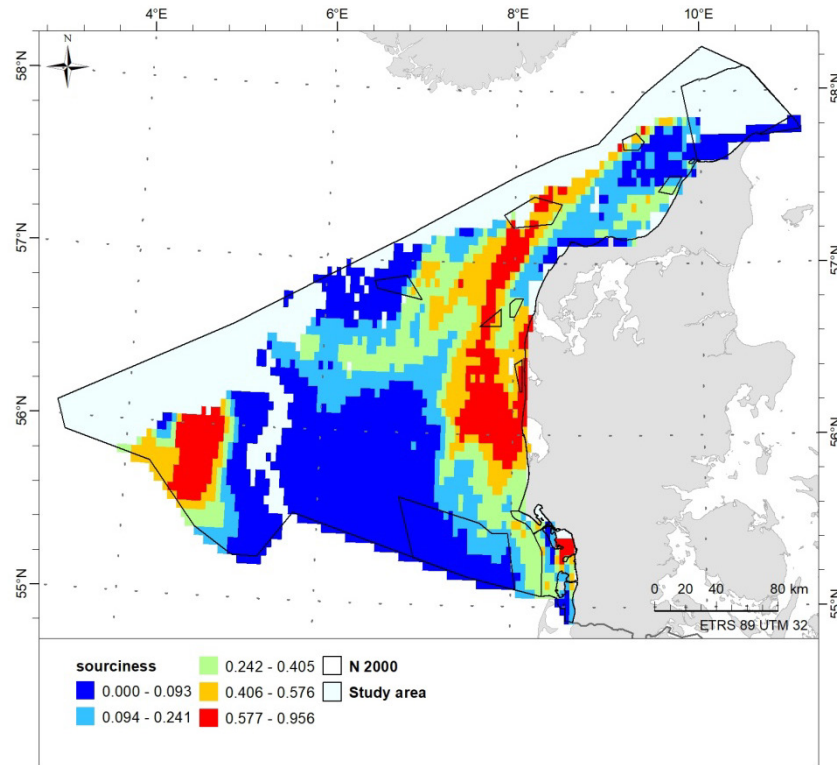
a)



b)



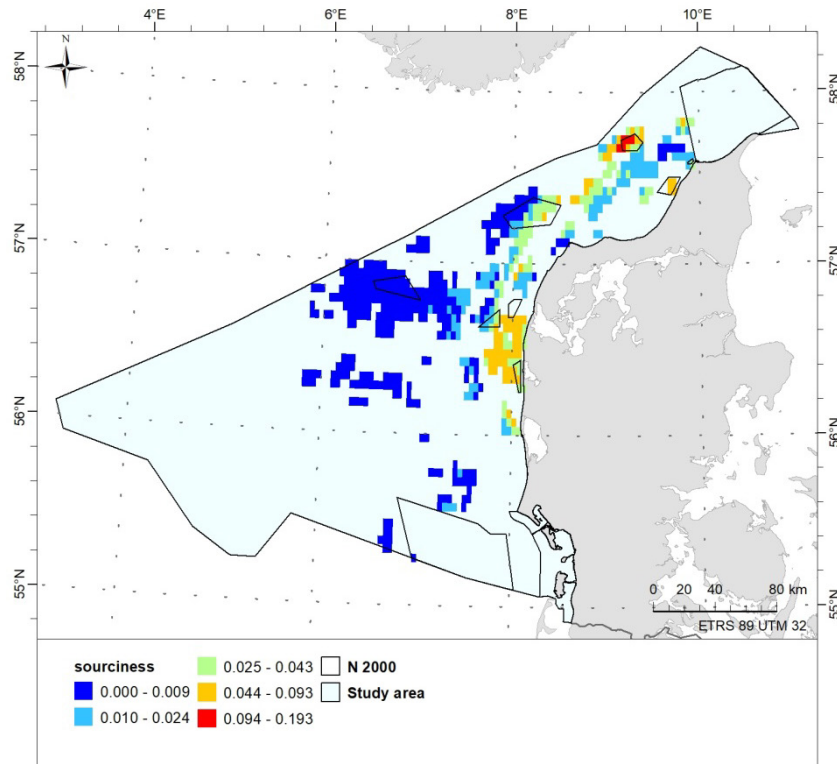
c)



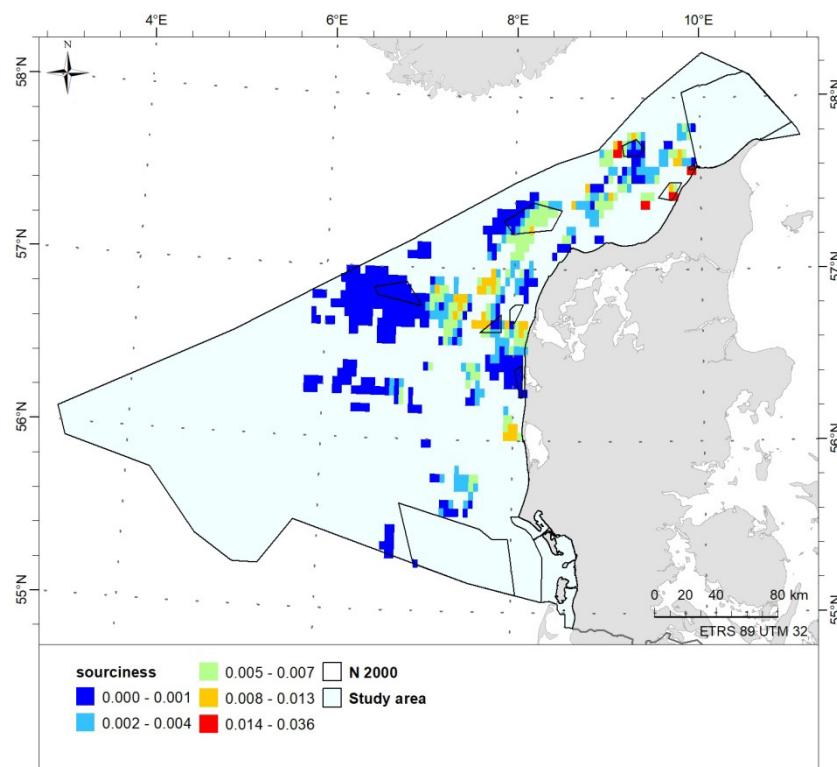
d)

Figure 44 Simulated North Sea connectivity (from top and down): a) hard bottom (brown algae), b) hard bottom (*Flustra*), c) soft bottom deeper than 50m and d) soft bottom shallower than 50m.

In the next 4 maps in Figure 45, the effect of different release periods (trait variability), transport durations and larval behaviour for larvae produced in hard bottom areas are shown for the North Sea hard bottom (*Flustra*) from top and down: a) month 3, 15 days, passive; b) month 3, 45 days, passive; c) month 6, 15 days, passive; d) month 3, 15 days, confined to above mixed layer.



a)



b)

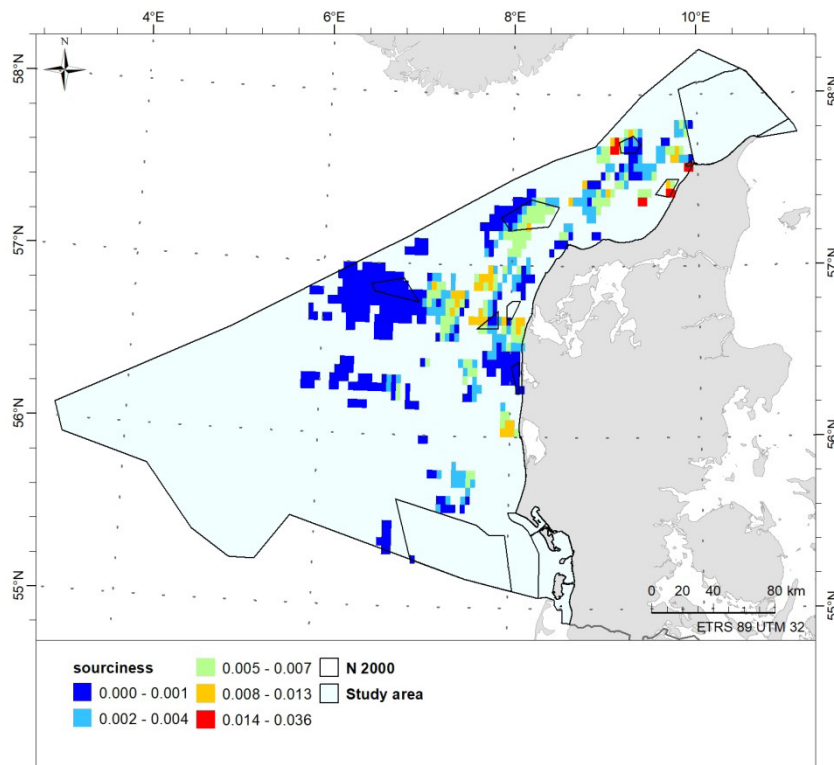
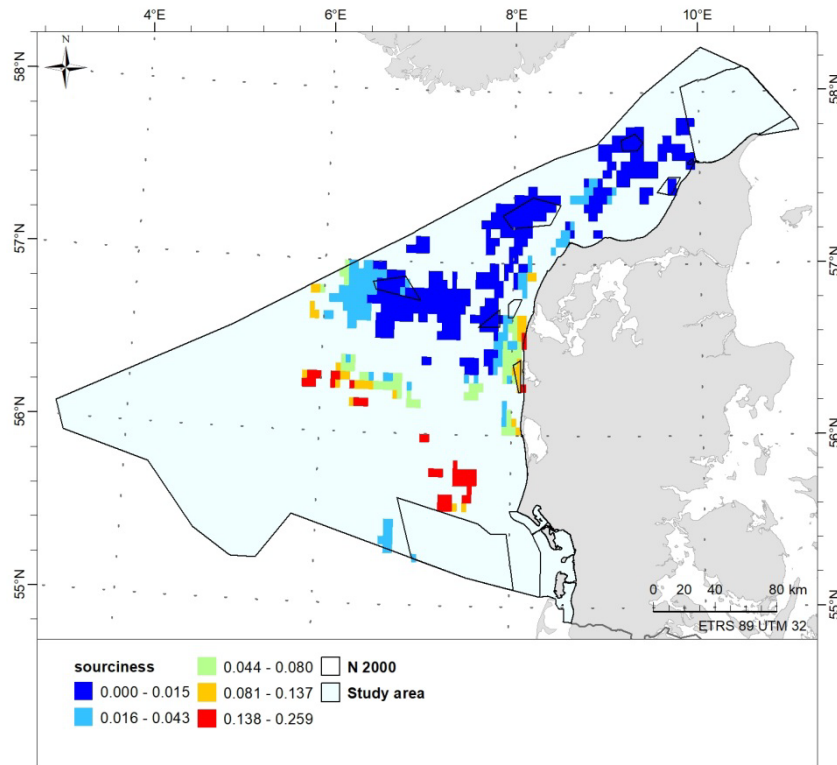
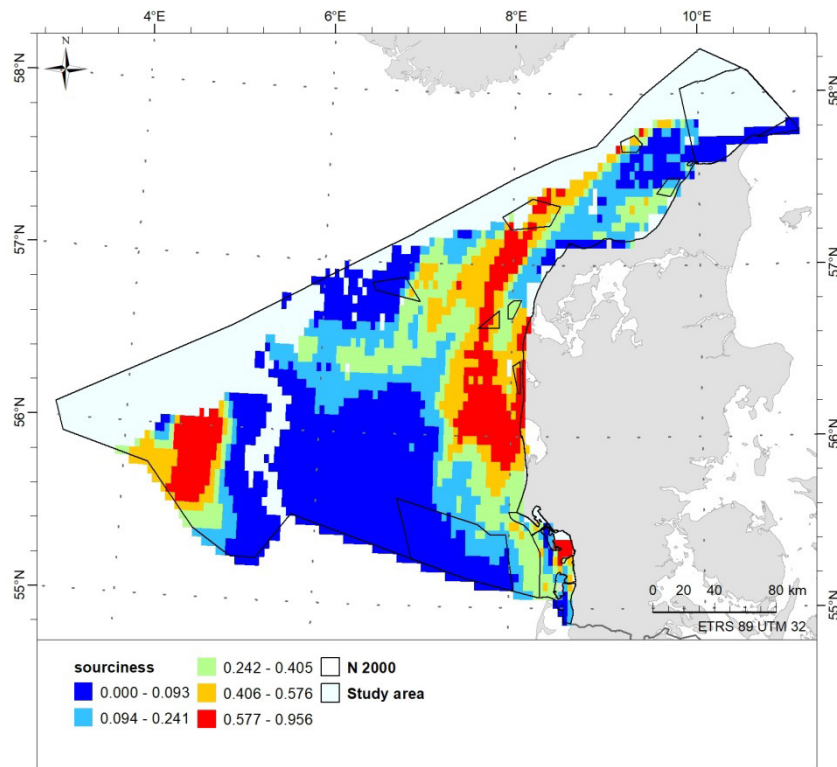
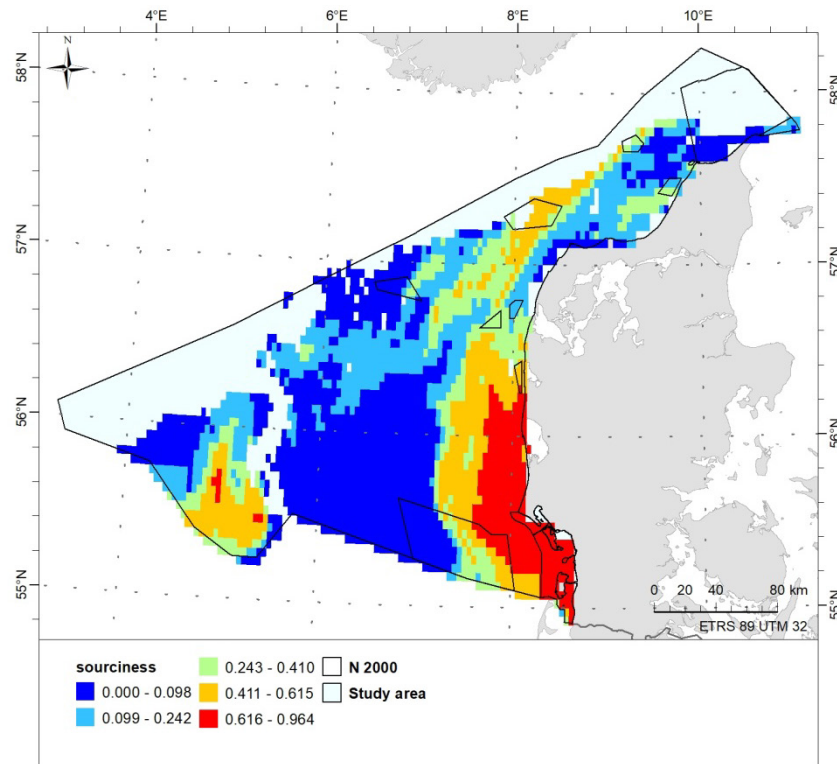


Figure 45 Trait variability for North Sea hard bottom (*Flustra* from top and down: a) month 3,15 days, passive ; b) month 3 ,45 days, passive; c) month 6,15 days, passive; d) month 3,15 days, confined to above mixed layer.

And finally, in Figure 46, the trait variability for North Sea soft bottom shallower than 50m is given from top and down: a) month 3, 15 days, passive; b) month 3, 45 days, passive; c) month 6, 15 days, passive; d) month 3, 15 days with the volume confined to above mixed layer.



a)



b)

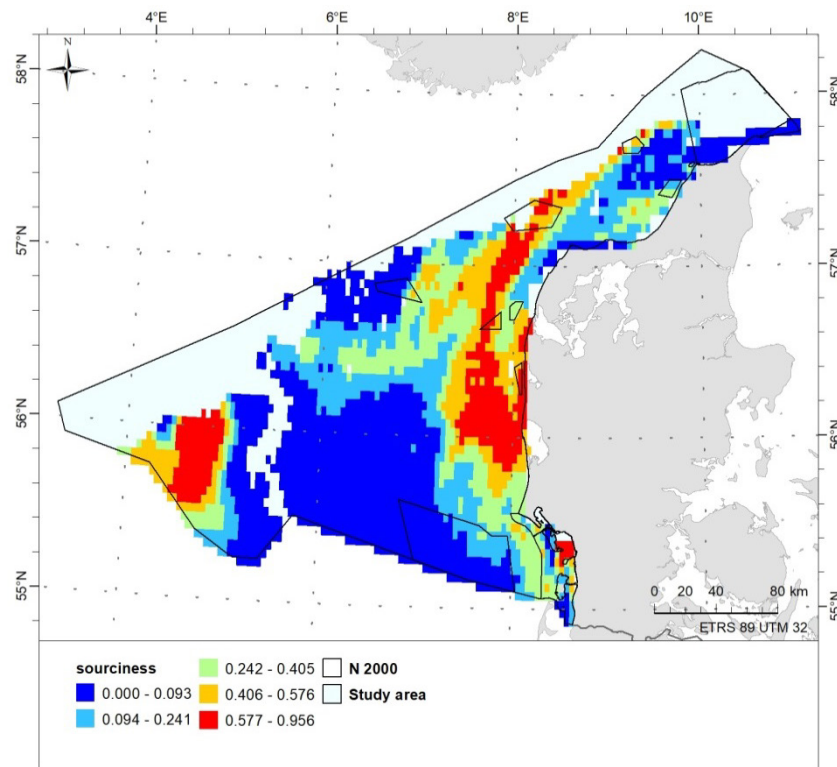
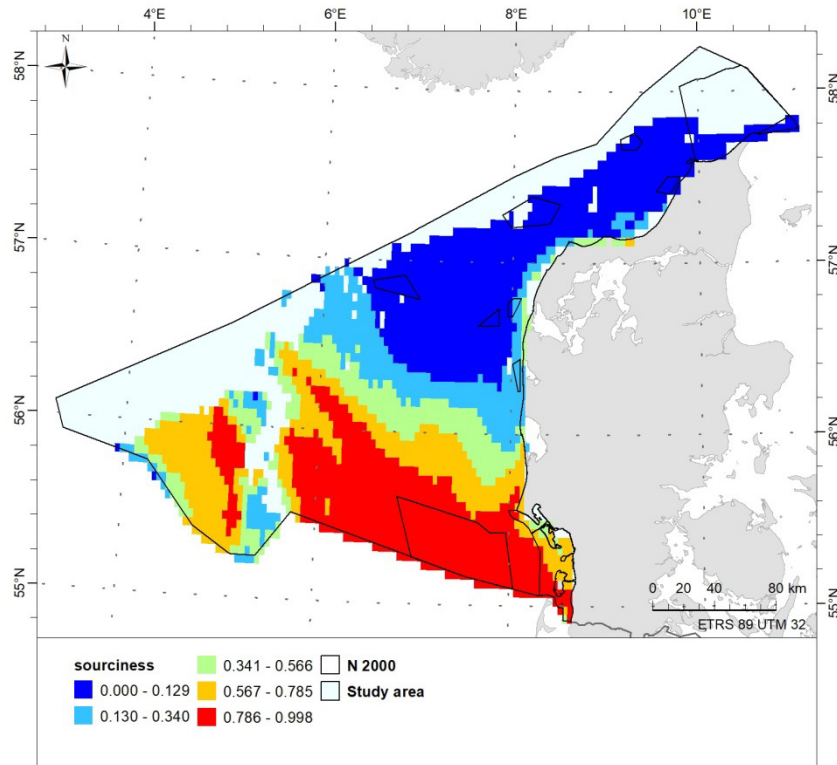
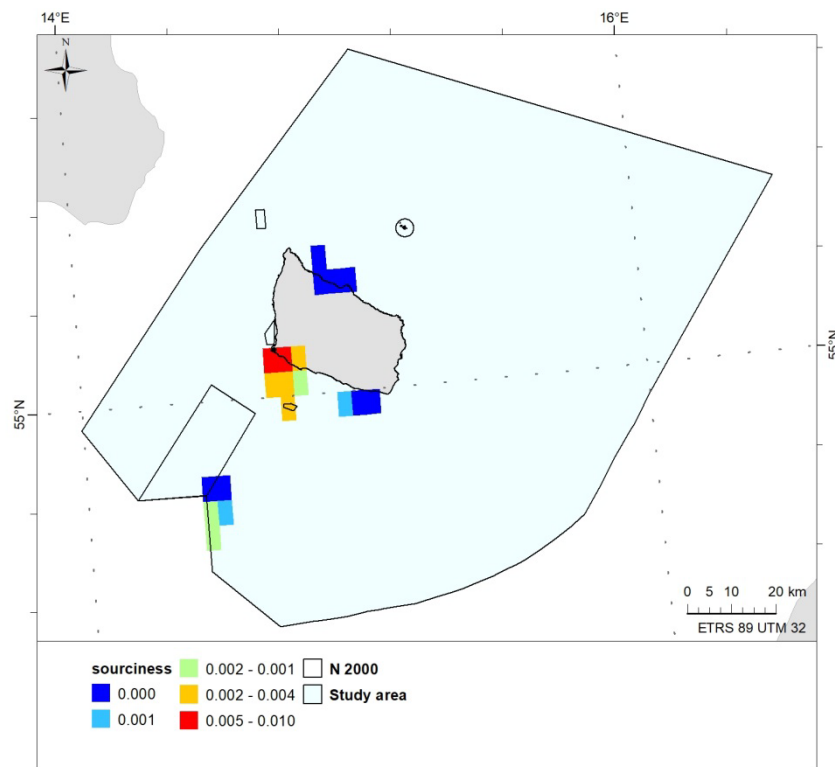


Figure 46 Trait variability for North Sea soft bottom shallower than, from top and down: a) month 3, 15 days, passive; b) month 3, 45 days, passive; c) month 6, 15 days, passive; d) month 3, 15 days, confined to above mixed layer;

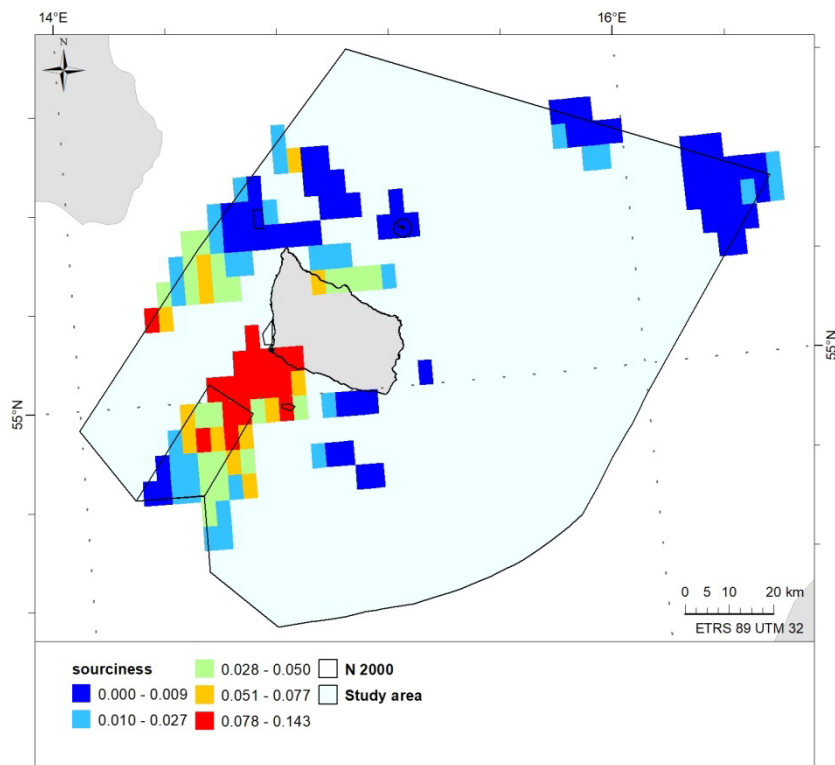
7.2 Baltic Sea

The results of using IBMlib to model the 'sourciness' of each location in the Baltic zone are shown in Figure 47 to Figure 49. These figures are meant to illustrate the effect of releasing larvae in the four different habitats (Figure 47), and the effect of different release periods, transport durations and larval behaviour for larvae produced in the hard aphotic bottom (Figure 48) and the sandy soft-bottom (Figure 49), respectively. As in the North Sea zone the results obviously depend a lot on the traits of the larvae, but the general picture emerging is that the weaker currents in the Baltic increase the 'sourciness' of the different habitats. Larval release month and transport duration are less important than in the North Sea, although a longer larval transport period obviously result in a relatively lower 'sourciness'. The hard bottoms all have a high 'sourciness'. For the soft bottoms the slightly shallower area south and east of Bornholm is an important source area.

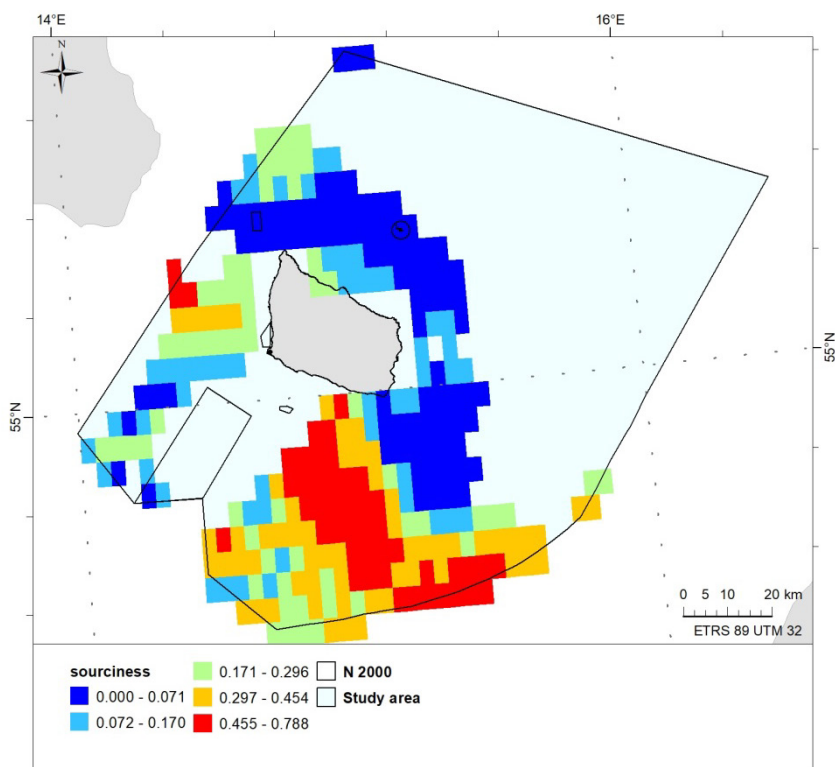
In the first 4 maps for the Baltic Sea in Figure 44 and Figure 47, the Baltic Sea connectivity is simulated for larvae released in month 3, with a pelagic duration of 14 days, and behaviour for sediments (from top and down): a) hard bottom *Furcellaria*+*Mytilus*, b) hard bottom *Mytilus*, c) soft bottom type *Saduria* and d) shallow soft bottom type *Hediste*.



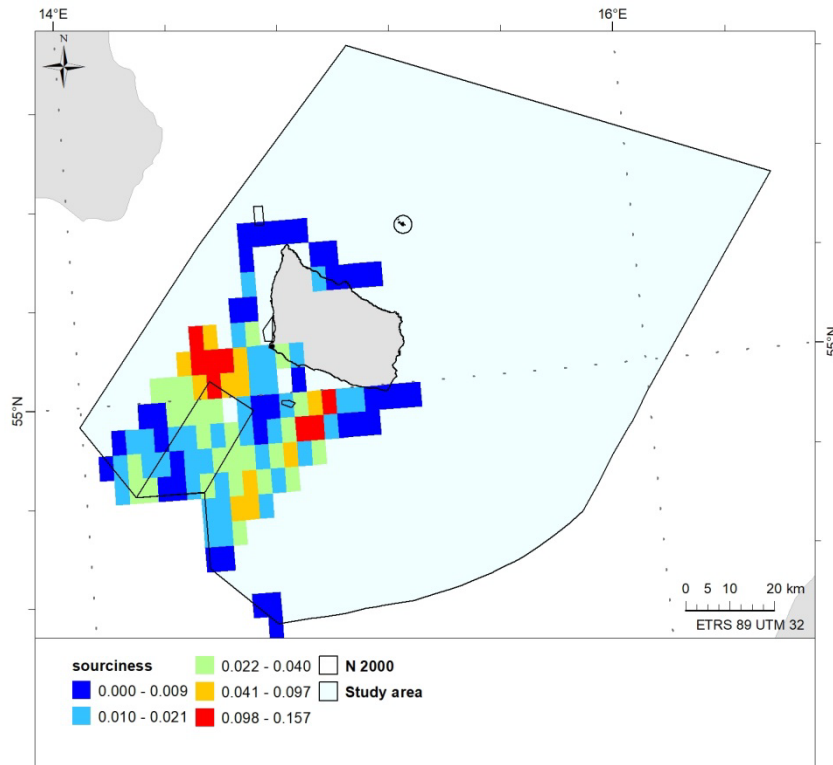
a)



b)



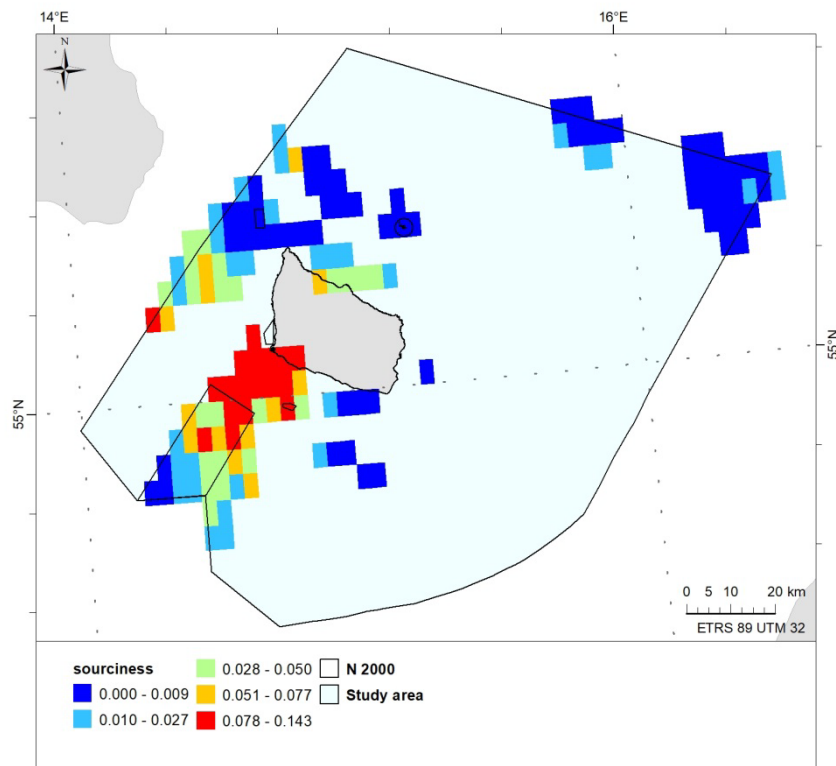
c)



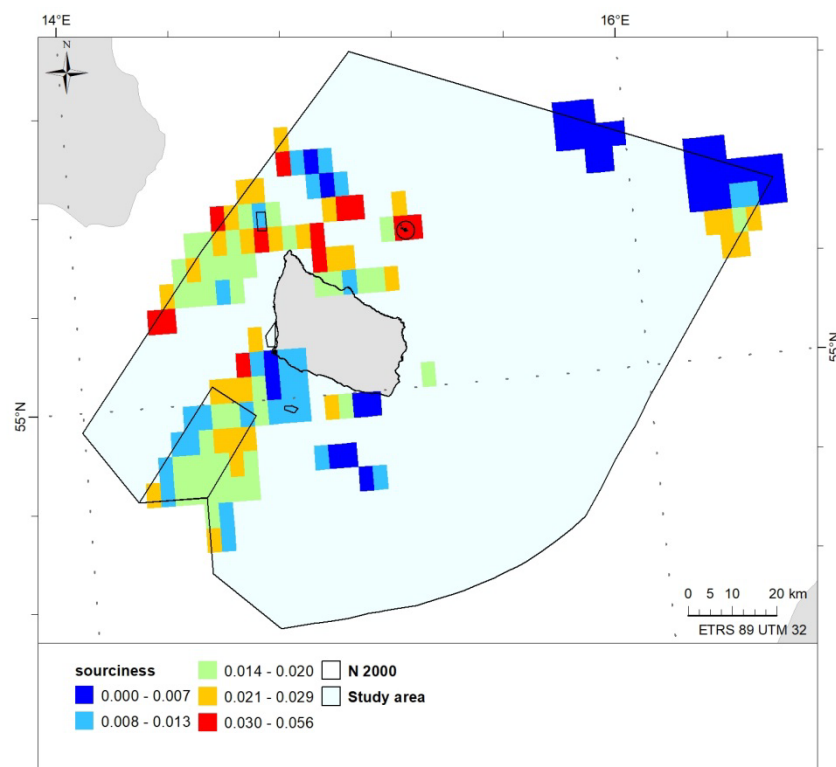
d)

Figure 47 Baltic connectivity for larvae released in month 3, with a pelagic duration of 14 days, and behavior for sediments (from top and down): a) hard bottom *Furcellaria+Mytilus*, b) hard bottom *Mytilus*, c) soft bottom type *Saduria* and d) shallow soft bottom type *Hediste*.

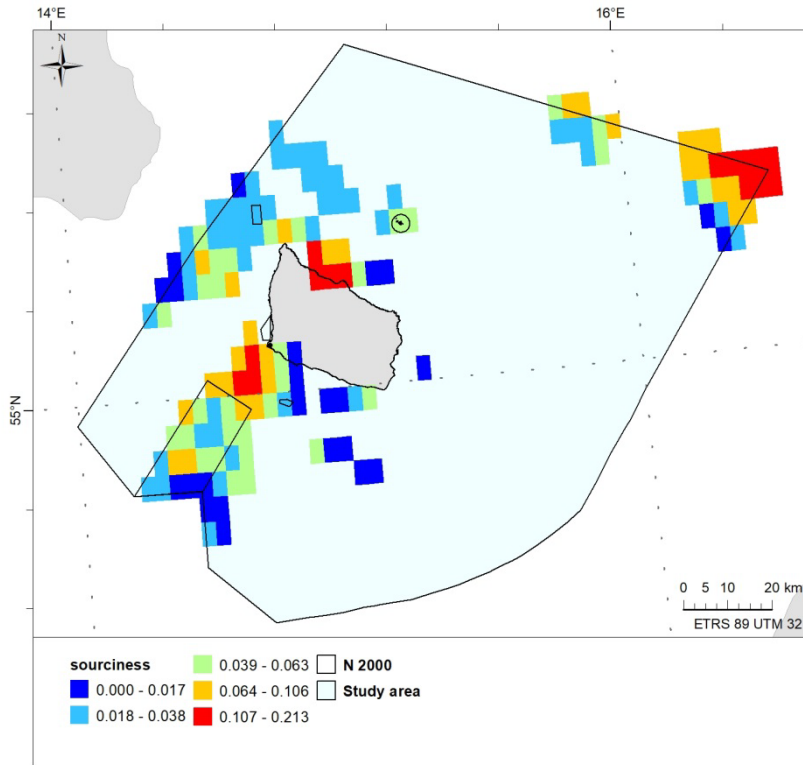
In the next 4 maps from Figure 48, the effect of different release periods (trait variability) in the Baltic Sea is shown for deep hard bottom *Mytilus* with traits = (release month, pelagic duration, behavior), from top and down: a) month 3, 15 days, passive; b) month 3, 45 days, passive; c) month 6, 15 days, passive; e) month 3, 15 days, confined to above mixed layer.



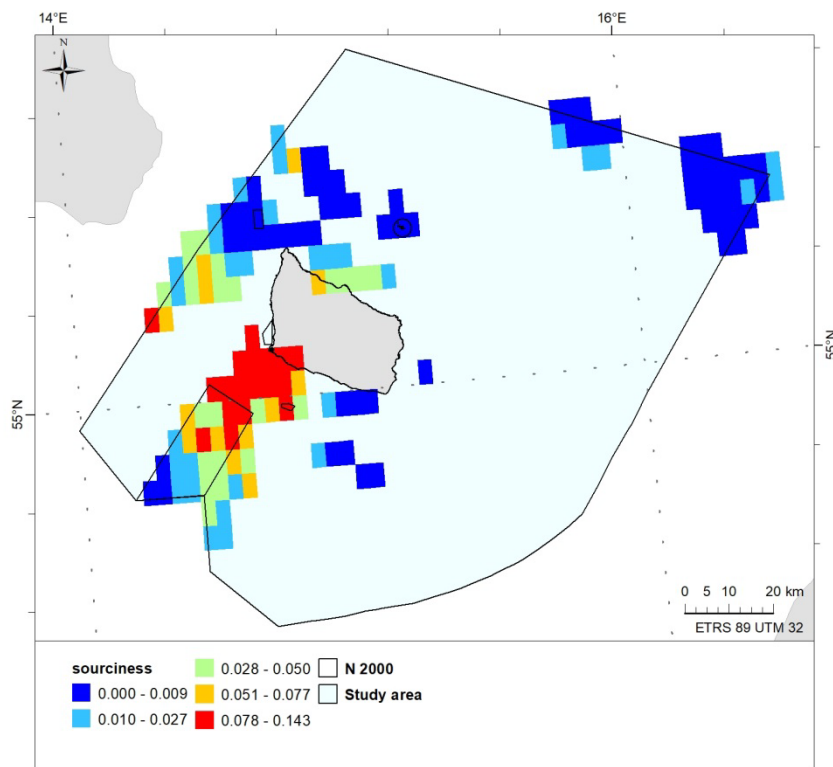
a)



b)



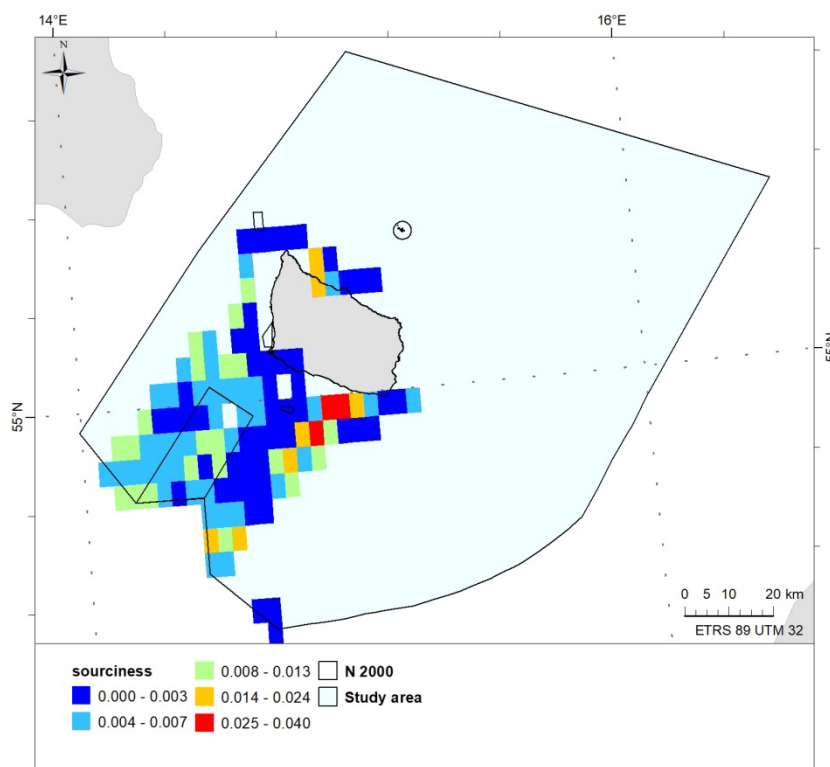
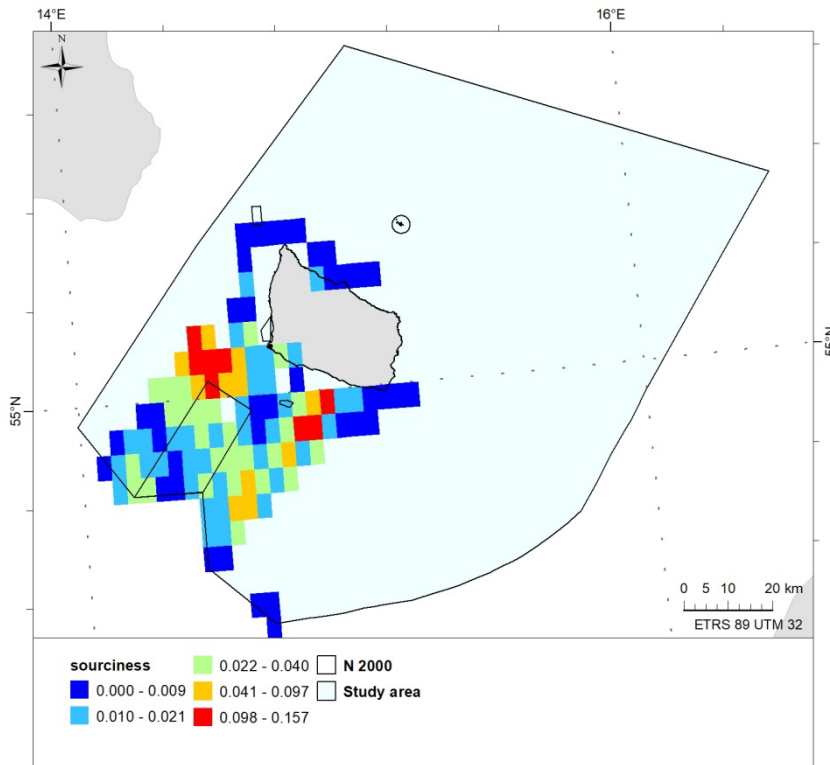
c)

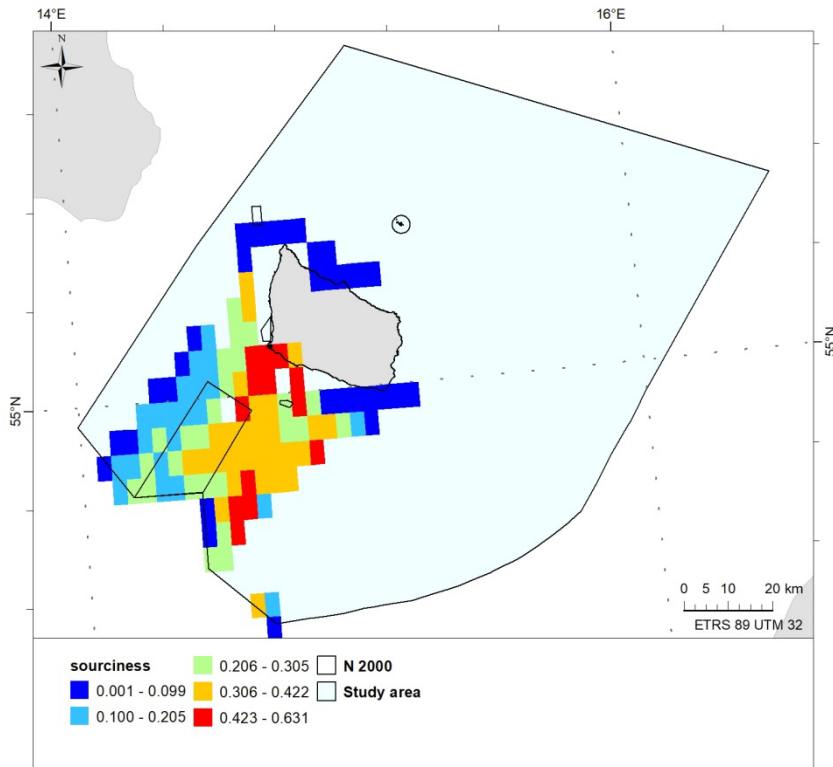


d)

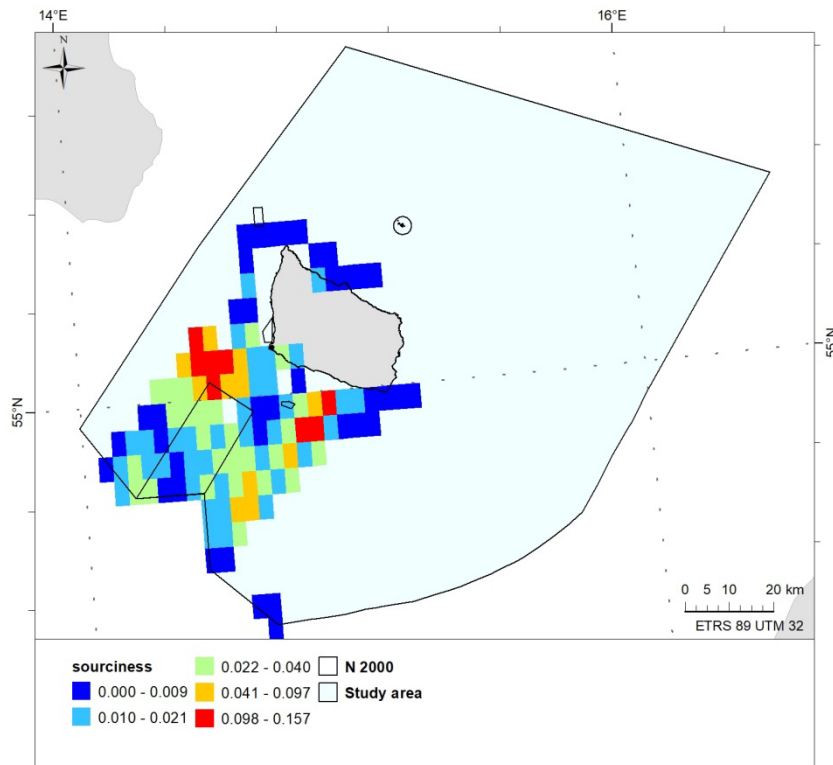
Figure 48 Trait variability for Baltic Sea deep hard bottom *Mytilus* with traits = (release month, pelagic duration, behavior), from top and down: a) month 3, 15 days, passive; b) month 3, 45 days, passive; c) month 6, 15 days, passive; e) month 3, 15 days, confined to above mixed layer.

In the last maps for the Baltic Sea, in Figure 49, the trait variability for the Baltic Sea is shown for shallow soft bottom type *Saduria* with traits = (release month, pelagic duration, behavior), from top and down: a) month 3, 15 days, passive; b) month 3, 45 days, passive; c) month 6, 15 days, passive; d) month 3, 15 days, confined to above mixed layer).





c)



d)

Figure 49 Trait variability for Baltic Sea shallow soft bottom type *Saduria* with traits = (release month, pelagic duration, behavior), from top and down: a) month 3,15 days, passive; b) month 3, 45 days, passive); c) month 6,15 days ,passive; d) month 3,15 days, confined to above mixed layer).

8. Biodiversity hotspots and systematic protection planning

In this chapter, we describe the concept of biodiversity hotspot and systematic conservation planning with examples from the marine environment, and considerations related to this study.

8.1 What is a biodiversity hotspot?

The British ecologist Norman Myers defined the biodiversity hotspot concept in 1988 to address the dilemma that conservationists face: what areas are the most immediately important for conserving biodiversity? In Myers original definition hotspots were geographical regions with richness of endemic species undergoing risk of habitat loss (Myers 1988 & 1990). With time, researchers have expanded the concept to describe geographical areas with high species richness, species endemism, number of rare species, threatened or endangered species, complementarity, taxonomic distinctiveness or degree of habitat loss (Reid 1998, Roberts et al. 2002, Brummitt & Lughadha 2003, Possingham & Wilson 2005). Thus, areas are considered biologically valuable for a number of reasons. The challenge is how to identify hotspots.

Marine conservation has historically lagged behind terrestrial conservation, because species, habitats and anthropogenic threats are less visible in the sea than on land, and we thus know more about response of terrestrial ecosystems than about marine ecosystems. Terrestrial conservation approaches are area-based and aim to conserve the target resource within a spatial boundary. Marine conservation has initially taken the same area-based approach with initiatives such as marine spatial planning and marine protected areas (Briscoe et al 2016). This may be a suitable approach in some habitats which are mostly static in nature and inhabited by sessile organisms such as shallow and coastal habitats (i.e. seagrass beds, macro algae habitats, and rocky intertidal zones) that fit well into terrestrial hotspot characterizations. However, open marine areas are far more dynamic and complex in processes, scales, and anthropogenic threats than most terrestrial systems (Maxwell et al. 2015).

In the open sea, dynamic coupling between physical and biological processes distribute interactions away from geomorphic features, and over much larger spatial and shorter temporal scales (Hyrenbach et al. 2000). For example biophysical processes such as upwelling, frontal gradients, and eddies create areas with high levels of primary production that stimulate complex trophic linkages. The predictable formation of these features allow species to repeatedly exploit these areas during predictable times of the year (Hyrenbach et al. 2000, Croll et al. 2005, Sydeman et al. 2006, Foley et al. 2010, Scales et al. 2015, Pikesley et al. 2013). In the sea highly productive areas are not necessarily linked to higher levels of biodiversity. Some of the most productive upwelling areas are relatively low in species richness, and temperature and stability, rather than primary production per se, seem to be important factors contributing to high biodiversity (Tittensor et al. 2010, Valentine & Jablonski 2015).

In many areas exploitation has resulted in significant declines in populations of commercially important species (e.g. Worm et al. 2009) and has negatively impacted non-target species unintentionally caught in fishing operations (e.g. seabirds, and marine mammals) (Lewison et al. 2004, Myers et al. 2007, Schipper et al. 2008). Habitat destruction is a primary threat to both terrestrial and marine benthic ecosystems. For the open sea, overexploitation may be the most important threat to top predators and vulnerable species (Pauly et al. 1998, Carr et al. 2003, Norse & Crowder 2005, Worm et al. 2006, Myers et al. 2007, Halpern et al. 2008, Heithaus et al. 2008, Jackson 2008, Schipper et al. 2008, Baum & Worm 2009, Hazen et al. 2013).

Productive areas such as upwelling regions account for only 0.1% of the ocean surface (Ryther 1969), yet they support up to 50% of the world's fisheries production (Valavanis et al. 2004). However, overexploitation does not necessarily occur in species-rich areas of the sea (i.e. coral reefs).

Consequently, a focus on biodiversity alone in marine conservation planning will fail to protect some of the most important areas of the sea. Therefore, in addition to species richness hotspots, dynamic features such

as pelagic hotspots generated by biophysical mechanisms that promote high production are critical for identifying areas of high ecological importance and thus of conservation concern (Hazen et al. 2013).

8.2 Marine protection planning

While the concept of biodiversity hotspots is a useful and easily understood basis for conservation planning, the actual prioritization, minimization of impacts for existing and future users as well as on-the-ground actions require some systematic planning. Systematic conservation planning involves the prioritization of sites with respect to their biodiversity or ecological value, identification of conflicting socio-economic interests, and implementation of strategies and actions that secure the long-term good environmental status of the sites. Several decision support tools for systematic conservation planning have been developed to guide the location and design of protected area networks and balance the competing conservation, social and economic interests; examples are Marxan and Zonation as used in this study. This chapter is concerned with identification of ecosystem hotspots, while the areas of socio-economic importance are described in chapter 0.

The objective in this report is to identify areas that can contribute to networks of marine protected areas that are coherent, representative and adequate for the protection of biodiversity in the Danish part of the North Sea, Skagerrak, and Baltic around Bornholm. It is important to ensure that a representative range of biodiversity and biological features are protected, which means that it may not be relevant to protect the area with highest diversity, but rather to protect a combination of areas that are representative of the biodiversity. The rank priority maps resulting from these analyses can subsequently be used to locate and list top-priority sites.

For operational use, it is necessary to understand why the priority of a certain site is listed as high or low. The priority ranking not only reflects the biodiversity features included, but also the choices made that influence the ranking (weights) for example of connectivity and other ecological features. In most analyses the biodiversity features (input data) have by far the largest effect on the priority ranking; thus our ability to understand the results relies on knowledge about the input data. The choices of what data to include are determined by the objective of the study as well as availability of information. For example if the objective is to focus on protection of specific species groups of threatened or rare species, these would be the only groups that should be included. The inclusion of a very large number of features of low importance will dilute the influence of important features and may therefore reduce the usefulness of the results. Thus, the choice of features to include is a very important step in the analyses.

Biologically important areas in the marine environment can be divided into three types: 1) important life-history areas, 2) areas of high biodiversity and/or abundance of individuals and 3) areas with high productivity, trophic transfer, and biophysical couplings (Hazen et al. 2013, Dowe & Brodeur 2004, Sydeman et al. 2006, Santora & Veit 2013). Important life-history areas can for example be feeding areas, spawning areas and juvenile settling habitats. For example, seagrass beds can serve as settlement area for pelagic fish (Ford et al 2010). Overall, it is desirable to consider a number of features that jointly represent biodiversity (Lehtomäki et al. 2016), but how these features are weighted can obviously have a large impact on results. Giving all features equal weight (e.g. 1.0) means that all features are assumed to be equally important and this may not be adequate.

Typically two types of situations are related to weighting; 1) when all features are of the same type, e.g. all marine mammals, the issue is relatively simple and weighting can be used to prioritize for example endemic species, threatened species, species of economic interest or other species. Lower weight can also be given to low-quality data; or 2) when biodiversity features are across more than one type, Lehtomäki et al (2016) suggest that a top-down approach to weighting can be followed, for example weighting present distributions higher than predicted future distributions, or, if species, habitats and ecosystem services features are

included, to weight species and habitats higher than ecosystem services, or endemic species higher than other species.

Examples of how biodiversity information can be weighted from the marine area include MPA network planning in New Zealand as documented in Geange et al (2017). Biodiversity features included were 15 community layers describing variation in benthic community composition to depths of 2000m, 16 community layers of fish community composition and a set of layers describing 71 inshore reef fish species. In addition, they included two components of connectivity and weighted the community layers higher than the individual species layers, due to higher species richness represented by these layers. For other examples see for example Leathwick et al (2008), Weeks & Jupiter (2013) and Magris et al (2015).

Our analysis is primarily concerned with biodiversity representation and complementarity and includes aspects of adequacy and connectivity. The degree of replication, can together with other MPA design principles, be assessed in post-processing analysis (Kukkala and Moilanen 2013).

8.3 Considerations regarding this study

We have used the systematic conservation planning soft wares Zonation (Moilanen et al., 2005; Moilanen, 2007) and Marxan (Ball et al. 2009) to analyse various MPA themes and scenarios within the two marine areas. We use species distribution data, species communities and broader surrogate layers (e.g. pelagic fronts and benthic indexes) to identify biodiversity hotspots in the Danish parts of the Baltic Sea and the North Sea. Adequate grid sizes were ensured by model specific settings and matrices resulting from particle distribution modelling were used to produce maps of connectivity (See chapter 7). The analysis also includes socio-economic layers, as described in chapter 0. Where the ecological layers are given a positive weight, the socio-economic layers are weighted negatively. This secures that areas of high ecological value and little socio-economic value will have the highest overall value.

The lack of spatial data on important biological features is a general problem for management of marine biodiversity. Using relationships between abiotic factors and biota to predict patterns of species distribution or richness (called surrogates) is therefore a relevant alternative (McArthur et al 2010). Surrogate models are based on physical and chemical properties of a habitat or known relationships between organisms where distribution data are available for one taxonomic group.

To illustrate the usefulness of spatial mapping in marine planning we have used different tools to study three relevant overall themes. In Theme 1 we undertake an analysis of *general biodiversity hotspots* using all the data collected. This analysis is thus based on a wide range of species representing soft and hard bottom benthic species, pelagic species as well as key top-predators. The highly productive areas are represented by pelagic fronts described by currents, temperature and salinity as well as primary production. The broad approach of including a variety of organism and biological features ensured a broad representation of biodiversity. We used the analysis to also examine the strength of using surrogates by comparing analysis done using all data (Theme 1a) with the results of analysis done using only five surrogates to describe biological features in the Baltic (Theme 1b). In Theme 2 we investigate the effect of protecting soft bottom fauna from bottom trawling and other seabed impacting human activities. The second (2) theme was therefore focused on identifying hotspots for biodiversity in deep areas with soft sediments both above and below 50 m depth.

Finally, in Theme 3 we illustrate where spatial protection measures may be established to protect the ecosystem components not currently protected by Natura 2000 in accordance with the requirements of MSFD article 13(4) as described in Part 1, ie coherent and representative networks adequately covering the diversity of the constituent ecosystems. Table 1 provides an overview of the three Themes.

Table 1 Description of selected analysis themes (see also Table 2).

| Theme | Purpose | Ecosystem features/Costs |
|-------|---|---|
| 1a | Overall hotspots: Identify the most economically and ecologically valuable areas and the areas subject to the highest pressure from human activities | All |
| 1b | Overall hotspots based on surrogate layers: Investigate the correspondence between model runs for the Baltic based on different selections of layers | Surrogate ecosystem features |
| 2 | Protection of soft bottom habitats considering only human activities that have benthic relevance | Soft bottom related components & economic components that are related to soft bottom |
| 3 | Illustration of spatial protection measures securing general biodiversity features in accordance with MSFD article 13(4) requirements. | Ecosystem components that are not covered by Natura 2000 and Bird Directive & all economic interests and pressures |

As earlier mentioned, the choice of input data exerts a high impact on the resulting priority ranking, with the logical consequence that lack of data also impacts the results. In this study, information on some of the important species groups is missing. In the North Sea, information on the present state of macro-benthos communities is limited as is knowledge of fish in untrawlable areas as well as insufficient information about the distribution of most seabird species, harbour seals (except in the Wadden Sea) and grey seals. In the Baltic, the macro-benthos situation is slightly better thanks to the data from Gogina et al.(2015), but the data coverage of the area around Bornholm is limited and the spatial distribution of macro-benthos assemblages is therefore mostly extrapolated from samples collected outside the Danish area around Bornholm. The precision of the assemblage mapping is therefore questionable. Moreover, no quantitative information is available about the fish fauna on hard or rocky bottoms and the data to map seabird distributions are insufficient for most species.

The majority of information on bird abundances and distributions presented in this report derives from project-based surveys performed in differing spatial and temporal scale. These are surveys related to offshore wind farm establishment as well as data collected in relation to the Marine Strategic Framework Directive. The spatial coverage of surveys in the North Sea under the NOVANA program is very limited. For some surveys the estimated abundances and distributions have been modelled. In other situations, data are presented in the form of point themes of actual observations, and thus presenting information on the distribution of a species, while no direct density estimate can be derived from those data. The spatial modeling of abundances and distribution at fine geographical scale was performed using Generalized Additive Models (GAMs) with the incorporation of environmental variables influencing the distribution of the species (Petersen & Nielsen 2011). Since the available environmental variables only poorly explained the distribution patterns found, geographical coordinates were included in the variables. Therefore, extrapolation of abundances and distribution from the models could not be performed outside of the areas actually surveyed. For these reasons, the layers of bird distribution could not be presented for the entire Baltic and North Sea study areas of this project. The exception is the abundance and distribution of Long-tailed Duck in the Baltic study area. However, although caution should be taken when interpreting results because data are lacking for some relevant species/communities and this may bias the results, the model runs **are** pinpointing hotspots for the species and communities included and provides important information based on current knowledge.

When establishing the network of Natura 2000 areas under the Habitat Directive the principal aim was to protect reefs, sandbanks and shallow water ecosystems. Subsequently, the inclusion of disturbance to

unique biological communities in deeper soft sediments, which are not included in Annex 1 of the Habitats Directive, by fishing activities has increased the need to add such areas in the MPA network.

9. Methodology for combining ecological and economic data to identify hotspots and suitable sites for new MPAs

Based on four different modelling methods, IBMlib, Zonation, Marxan and DISPLACE, calculations of the ecological and economic consequences of various marine protected areas (MPA's) can be estimated. IBMlib is the initial model step, which estimates the connectivity matrix needed as input layer(s) by both Zonation and Marxan to address the connectivity between different areas. After a suitable area has been identified by either of the two models, it will be necessary to run DISPLACE to calculate, where the fisheries excluded from the MPA are likely to be fishing, and what the consequences may be for the biodiversity in the areas, where fishing pressure increases. Figure 50 gives an overview and describes the linkage between the four programs as well as the process of data handling.

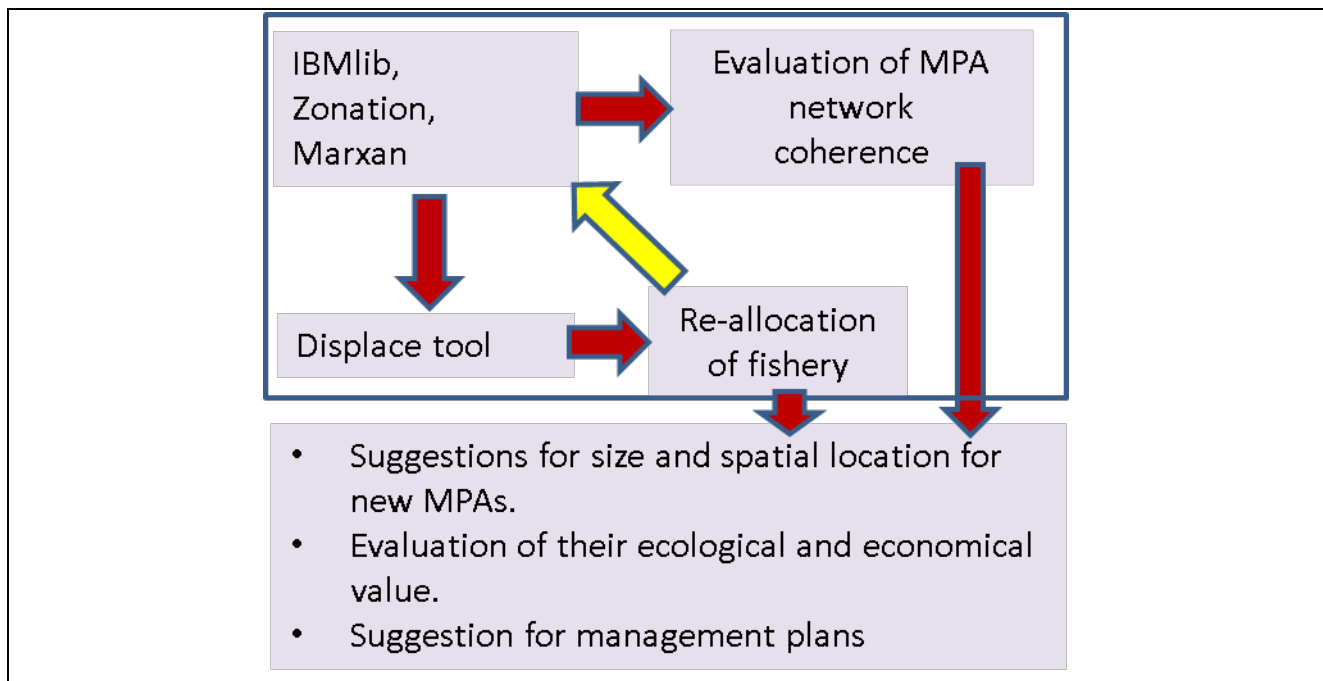


Figure 50 Analytic workflow for the model tools. The yellow arrow indicates a possible need for running the models several times to optimize the combined output from the site selection tools Marxan and Zonation and the Displace tool.

Marxan and Zonation are two widely used and well documented tools or decision support systems for systematic conservation planning and have been compared in several studies (e.g. Wintle 2008, Allnutt et al. 2011, Delavenne et al. 2012). Although, the two methods are both aiming at making spatial priorities for conservation by considering biodiversity features and economic interest, the approaches for meeting this aim, the algorithms used, are very different. While Marxan follows a “minimum set framework” to reach feature specific targets while avoiding conflicts and using the minimum area needed, Zonation is following the “maximal coverage framework” (Delavenne 2012). Zonation does not require defined targets for each ecological feature (although it is also possible to give targets); instead it produces a ranking of the whole landscape.

The targets used by Marxan in this study are percentages of the ecological features (not areas) to be protected. The models identify the most valuable areas for all ecological features combined. Where possible, the area covered will therefore be lower than the percentage of the target. If many conflicts occur in an area and only areas with lower ecological value can be selected, the selected area will be larger. If an ecosystem component consists of presence-absence data, e.g. the presence of a specific soft bottom type, the percentage is in relation to its area. But if an ecosystem component has different values, e.g. the distribution of harbour porpoise or connectivity data, the percentage is related to its summed up values and the selected area will therefore vary. Figure 51 illustrates 3 different cases for the combined selection of two ecosystem components. In the first example shows a case where the distribution is dense, but not overlapping. Example two shows a situation with a dense distribution and overlapping, which leads to small area. In example 3 the two ecosystem components are still overlapping but more widely spread, so the area needed to protect the same amount of the ecosystem is big larger.

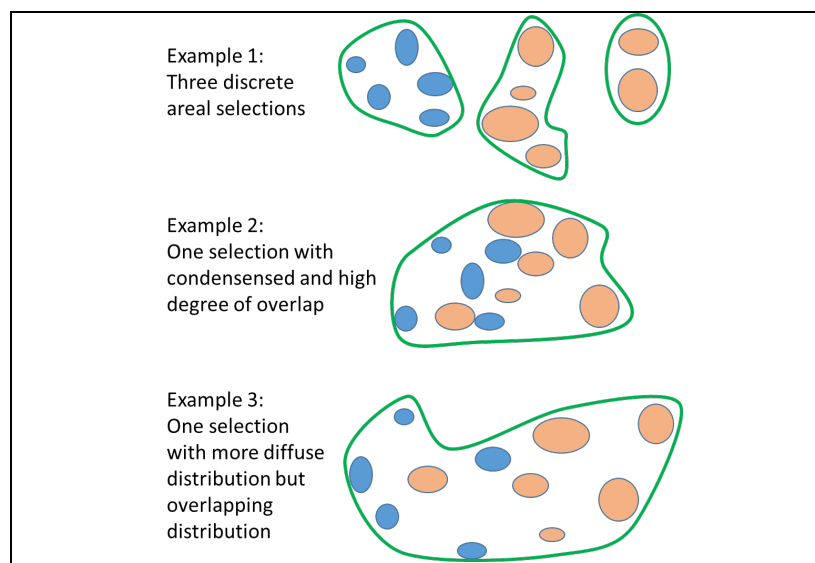


Figure 51 Theoretical example showing three different kind of possible selection of two ecological topics (illustrated by different colours) each having the same percentage target but different overall spatial coverage (feature blue cover less).

9.1 Zonation

The objective of Zonation is to iteratively identify areas with high complementarity that maximizes the representation of biodiversity features. Zonation starts with assuming that everything is protected and then iteratively removes the grid cells resulting in the smallest loss of biodiversity (or included features). The result is therefore a ranking of the landscape from 0-1 or from least valuable areas to most valuable areas. Based on the ranking it is possible to visualise the 5%, 10% or whatever threshold chosen of the most valuable areas (or least valuable areas) for conservation. When presenting the zonation results below the rankings are mapped as 10 classes, each class representing 10%. I.e. the class 0-10 in the maps represents the 10% least valuable areas, whereas 0.9 represents the 10% most valuable areas (Figure 52).

This percentage should not be mixed with the targets defined in Marxan, which are targets for each ecological feature (also called biodiversity). The second “standard” output from zonation (in addition to the rank map) is the performance curves that show how much of the feature-specific distributions that are remaining under decreasing level of protection (Moilanen 2007, Lehtomäki and Moilanen 2013). The

performance curves can be used to assess whether each feature is reaching a target of 20% under protection for example, this target can be compared to the 20% target of the Marxan. This means that based on the same analysis it is possible to assess a range of potential targets for each feature (an example of how to interpret a performance curve plot is given in Figure 53).

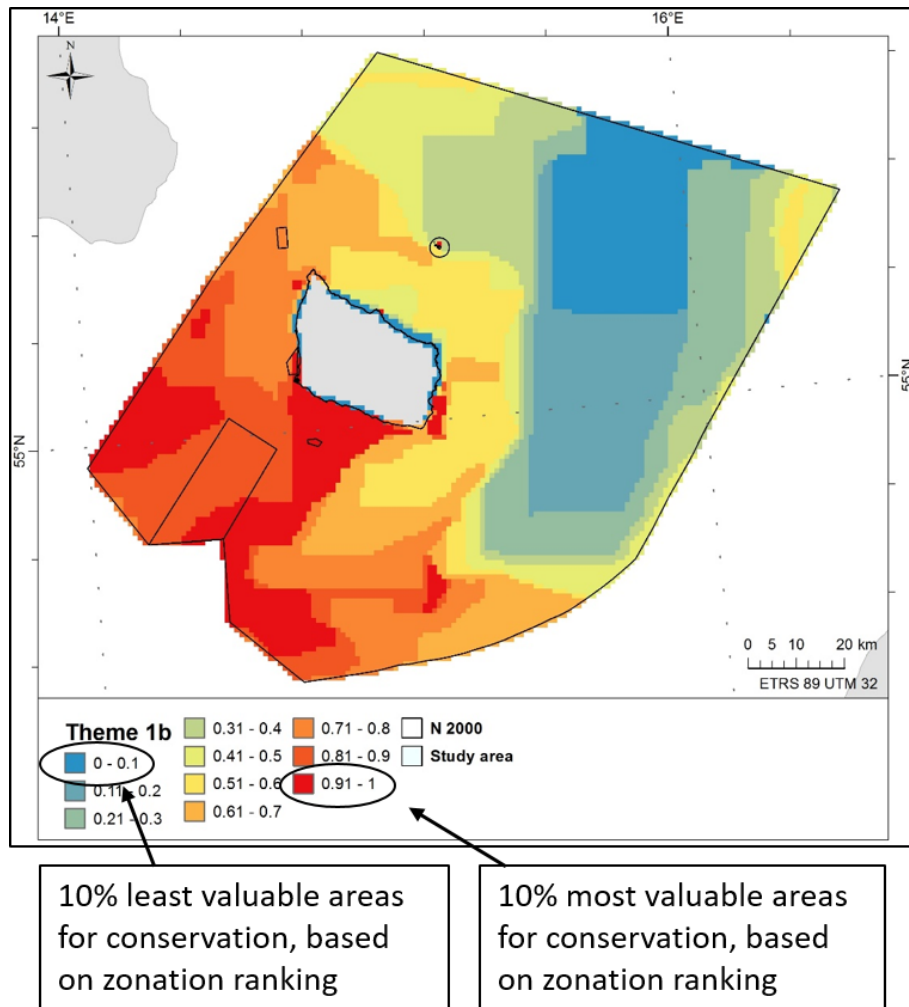


Figure 52 Example of how to interpret a zonation ranking map.

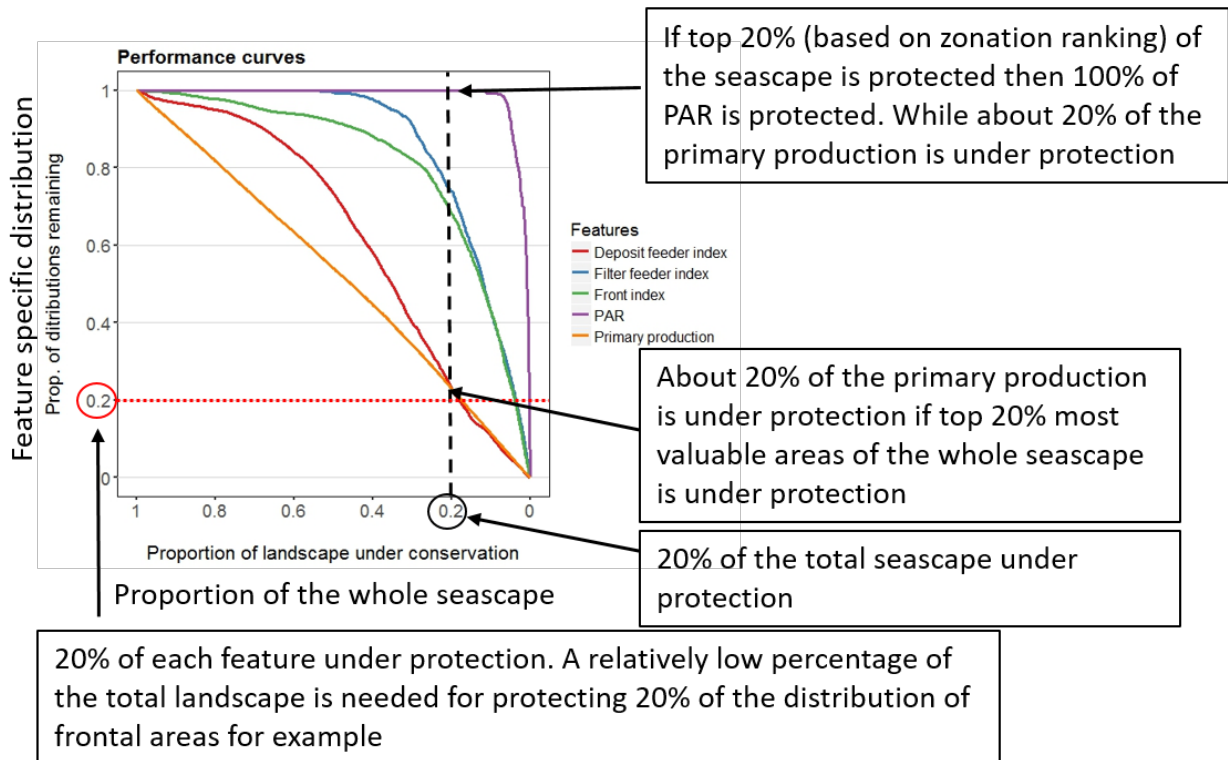


Figure 53 Example of how to interpret a zonation performance curve plot.

Zonation has two main components: the “zonation meta-algorithm” (the ranking algorithm, which is always the same) and the definition of the “removal rule” (or definition of marginal loss, which can be changed depending on the purpose of the project). There are three main removal rules to choose from:

- the core area zonation aiming at prioritizing all features
- the additive benefit function giving more emphasis to higher biodiversity (and thereby some species in low biodiversity areas might be under-represented)
- The target based function aiming at meeting feature specific targets. This approach is most similar to Marxan.

Zonation can handle different types of input features for example species suitability or probability, abundance or presence absence, communities and habitats or potentially other features describing “ecological important” areas. The important aspect of the feature is that higher values means higher biodiversity value as Zonation automatically normalizes the input variable before conducting the analysis. The input layers should be in a raster grid format with identical resolution and extent. It is possible to give feature specific weight and thereby for example give high emphasis on endemic or red listed species. Economic interest and alternative area use features can be included in the same way; however, they should be negatively weighted, thereby making the grid cells less suitable for conservation. Zonation has different further options for dealing with for example connectivity and aggregation and it is possible to use a hierarchical mask (for analyses of protected area expansions) or to exclude of “no go” areas (see the Zonation manual by Di Minin et al. 2014).

The simple setup for the different Zonation runs in this project is described below:

- For each “theme” (as specified below) we ran two scenarios:
 1. One with only the biodiversity features (species, communities and habitats and
 2. One with biodiversity features) and “cost” layers (economic interests or pressures)
- The additive benefit function is used in all scenarios
- The biodiversity features are all weighted equally (with one exception, see results below)
- The cost layers are weighted (negatively) so that they sum up to the same level as the biodiversity features and different groups of economic features get approximately the same weight, for example fisheries gets the same weight as shipping
- Areas not suitable for conservation (due to conflicting use, e.g. windfarms or oil and gas installations) were excluded from the analyses, because the selection is solely based on nature protection.
- One cell at a time was removed (wrap factor = 1) from the edge of the remaining seascape (Edge removal = True),
- A boundary length penalty was set to 0.05 to reduce “fragmentation” of the result
- Connectivity is handled by the biodiversity features for soft and hard bottom communities

Zonation is flexible and very useful as a decision support system as a) it does not need targets, b) creates a complete ranking of the seascape/ landscape, c) has different removal rules, d) possibility to weight features and costs, and further e) also is easy to use with a simple graphical user interface. The weights of the targets can easily be adjusted to prioritize certain biodiversity features or economic interests. The performance of Zonation can easily be assessed based on the resulting performance curves. It is nevertheless important to remember that the results will never be better than the input data, and that the results only reflect the high value areas based on the features used in the analyses. Zonation is an open source program and can be downloaded from www.helsinki.fi/en/researchgroups/metapopulation-research-centre/software \l "section-14300. The post-processing of the zonation results were done in the r-package “Zonator” (Lehtomäki 2016).

9.2 Marxan

Marxan is also an open-source software designed to facilitate systematic conservation planning. The iteration algorithm in Marxan optimizes a network of MPAs based on ecological and socio-economic spatial data and user defined criteria. In comparison to Zonation, Marxan is a minimum set algorithm, i.e. the main aim is to achieve a minimum representation of biodiversity features to fulfil the targets while avoiding conflicts with economic interests or pressures (Ball and Possingham 2000, Possingham et al 2000, Watts et al 2009).

Marxan works target-based and provides several solutions per target, assuming that not necessarily only one spatial solution exists in a planning area to fulfil the defined targets. Marxan runs therefore several times (in this project 100 times) per scenario. Every run results in a solution, which can be chosen for itself. Since it is not feasible to show all 100 solutions, in the following maps, the mathematically most optimized solution, the so-called “best solution”, and the selection frequency for grid cells for all 100 runs are shown. A selection frequency of > 50% is considered as a significant solution (Leslie et al 2003; Peckett et al 2014). The mathematical difference between “best solution” and the other solutions is most often marginal and the locations selected will therefore vary considerably from run to run. Additionally, Marxan provides summary data per scenario about the area selected, targets reached, and conflicts with the other features.

In Marxan (without Zones) all conflicts with the targets as e.g. the economic interests, impacts, are collected in one cost layer.

The general setup for Marxan was as follows:

- For each “theme” (as specified below) we ran two scenarios 1) with only the biodiversity features and 2) with biodiversity features (species, communities and habitats) and “cost” layers (economic interests or pressures).
- The targets were the same for all ecosystem components with the exceptions as described in the results
- The cost layer was weighted so that it sums up to the same level as the biodiversity features and also that different groups of economic features get approximately the same weight, for example fisheries gets the same weight as shipping.
- Areas not suitable for conservation (due to conflicting use, e.g. windfarms or oil and gas installations) were excluded from the analyses, because the selection is solely based on nature protection.
- The Boundary Length Modifier was initially set to 2 but needed calibration in some cases. It was increased for theme 1a without costs in the North Sea and decreased for theme 1a and 3 with costs in the Baltic Sea.
- 100 runs per scenario
- For the iteration, the default settings were used. Where necessary, the number of iterations was increased to guarantee stable results.

The model results from Marxan are not the final solutions, but need to be modified by the planner. So manual adjustment (= human planning) would be the best approach to designate areas in a “final” suggestion. This postprocessing is not carried out in this report.

Marxan can be downloaded from <http://marxan.net/>.

9.3 General criteria for selection/Scenario matrix

Three main analysis themes (or groups of model scenarios) were defined in conjunction with the Ministry of Environment and Food (MFVM), the Environmental Protection Agency (MST) and the Ministry of Foreign Affairs (Fish Agency). All themes were modelled both with Zonation and Marxan. The results from Zonation are called hotspots, as complete priority ranking maps are shown. The results by Marxan show the results for clearly selected areas which can be taken as basis to designate new MPAs. For this purpose, clear targets are needed. Since they are not yet set by managers/politicians, a set of scenarios for protecting 5%, 10% or 20% of the single ecosystem components was modelled for all themes. If it is possible to select high quality areas (with higher than average values for the ecosystem components), less than either 5%, 10% or 20% of the area is needed. If on the other hand, only areas with low quality for the ecosystem components can be selected, e.g. to avoid conflicts, more area is needed for the same protection targets.

The results from Zonation can be used in a similar way for selecting the most valuable areas based on the final cell ranking for example 20% highest ranked cells, and then by assessing the performance curves it is possible to assess whether the 20% target for each feature is protected, or if not how much is actually protected. The results differs to varying degree because the two tools uses different algorithms for selecting the “best areas”, different selected areas (by each approach) can also potentially result in similar level of protection, i.e. different results do not mean that one of the models is wrong. However, compared to Marxan, the performance of Zonation can be directly evaluated based on the performance curves showing how much of a feature that is covered by the selection of a given percentage of the total area. Marxan on the other hand takes into account that several spatial solutions are possible to reach the same target.

The aim of the first theme is to describe the most valuable areas for conservation based on all available (collected) data in this study, both with and without considering costs and pressures (theme 1a). Within this theme a scenario called theme 1b is also included, where only surrogate layers are used. This theme was chosen with the purpose of describing, what a defined set of surrogate layers can achieve. Further, it also indicates, whether the patterns are robust or not; if similar patterns are obtained using a different set of

ecological variables, it can be considered as a sign of robustness of the model solution. Due to the lack of sufficient surrogate layers for the North Sea, Theme 1b could only be modelled in the Baltic.

The second theme identifies areas that may be closed to protect benthic soft bottom biota affected by fishing gears that cause seabed abrasion, such as bottom trawls.

The third theme is a first attempt to identify areas that may fill gaps not covered by habitats and birds directives. It is focussing on benthic and pelagic ecosystem components and aims at establish spatial protection measures, contributing to coherent and representative networks of marine protected areas, adequately covering the diversity of the constituent ecosystems.

A detailed list of ecosystem components used for all three themes is described in chapter 9.4.1 and 9.5.1.

The themes and scenarios were developed based on part 1 of this report and on the meetings with Ministry of Environment and Food (MFVM), the Environmental Protection Agency (MST) and Fish Agency and are based on the following assumptions:

- The international evaluation of the Danish marine Natura 2000 network has concluded that the network is sufficient.
- The economic interests should all have the same value or importance

For all themes, similar scenarios will be modelled. For the hotspot analysis (Zonation) they will be:

- Hotspots including economic interests and impacts
- Hotspots avoiding economic interests and impacts

For the suggestion of new MPA (Marxan) scenarios include:

- Suitable new sites including economic interests and impacts, with the target 5%, 10% and 20% of the ecosystem components
- Suitable new sites avoiding economic interests and impacts, with the target 5%, 10% and 20% of the ecosystem components

The suggestions for new areas will most often coincide with the hotspots, but the chosen approach for hotspots from Zonation focusses on the overall ecosystem, while the focus for the suggested sites from Marxan is on covering every ecosystem component by the defined percentage.

Additional Products will be:

- The impacts relevant for the respective theme
- The economic interests (economic hotspots) relevant for the respective theme.

From theme 2, scenarios from both Zonation and Marxan with combinations of 5% and 20% closures in the North Sea and the Baltic were selected to run DISPLACE.

9.4 North Sea results of Zonation and Marxan

9.4.1 Area specific model input

The data used in the analyses have been described in Part 1 of the report. The model setups are described in the chapter above and layers with full coverage, considered suitable for the conservation planning exercise are listed in Table 2. Theme 1b was not included for the North Sea because surrogate layers are not available for bottom communities.

Ecosystem components:

- Due to lack of relevant recent data on the distribution of benthic communities we used the general result from Rees *et al.* (2007) and subdivided the soft bottom benthos into two depth intervals, above and below 50m of depth, as described in part 1, chapter 3.1.6 (soft bottom communities). We furthermore assumed that soft bottom benthos would be present all places where hard bottom had not been identified.
- Primary production, front index, hard bottom and marine mammals (harbour porpoise and harbour seal) as described in part 1.
- A bird species, Common scoter, as areas aggregated in 3 classes, in accordance to importance. This differs from the data in part 1. Other birds were not mapped in the whole area.
- Fish as represented by pelagic and demersal biomass and species richness.

Instead of using the respective model's own connectivity function, the connectivity in terms as sourciness was included as layers from the IBMLib model, similar to the approach suggested by Magris *et al.* (2015). Sourciness was calculated for the two soft bottom depth classes and for the hard bottom communities. The coastal area was extrapolated where necessary.

Human activities:

- Sediment extraction, Oil/gas installations, offshore wind power and fisheries
- AIS density quantified by shipping intensity, cables and pipelines, World War 2 (WW2) chemical munition dumpsites and military interests as described in chapter 0.
- For fisheries the first hand value of landings and the trawl swept area ratios were used

Dumping sites were not included in the analysis because information is only available as point data. In the Baltic Sea around Bornholm there is only one site, whereas in the North Sea, there are several sites. In contrast to oil and gas installations that are of the same size scale but connected by linear structures. The dumping sites exist as stand-alone locations without any connection and they are very small compared to the size of the analysed area.

Efforts were made to ensure a resembling effect of each feature in the respective models. The weighting of the ecosystem components takes into account the importance, data quality and the dominance of some features. These effects were examined in scenario 1a. The weights chosen for Zonation are listed in Table 2. For Marxan, targets for some layers were reduced in Scenario 1a and 3 as is described later in this chapter.

To achieve the similar weighing of different sectors, weights were set for the normalized cost layers in Zonation (Table 2). For Marxan and the identification of economically important areas, a slightly more complex approach was taken.

Table 2 Layers included in the different model runs, themes 1a, 2 and 3. SB = soft bottom and HB =hard bottom. Zonation weight of each feature is included in the specific theme (1a, 2 or 3). Theme 1b is not covered in this area. For a detailed description of the connectivity layers see chapter 7.

| Layer description | Type | 1a | 2 | 3 |
|--|----------------|----|---|---|
| Connectivity for deep soft bottom (>50m) released in March, pelagic duration 45 days | Soft bottom | 1 | 1 | 1 |
| Connectivity for deep soft bottom (>50m)released in March, pelagic duration 15 days | Soft bottom | 1 | 1 | 1 |
| Connectivity for deep soft bottom (>50m)released in June 15 days | Soft bottom | 1 | 1 | 1 |
| Connectivity for shallow soft bottom (<50m)released in March, pelagic duration 45 days | Soft bottom | 1 | 1 | 1 |
| Connectivity for shallow soft bottom (<50m)released in March, pelagic duration 15 days | Soft bottom | 1 | 1 | 1 |
| Connectivity for shallow soft bottom (<50m)released in June, pelagic duration 15 days | Soft bottom | 1 | 1 | 1 |
| Bubble reefs | Hard bottom | 1 | | |
| Connectivity HB community dominated by large brown algae and filamentous red algae released in March, pelagic duration 45 days | Hard bottom | 1 | | |
| Connectivity community dominated by large brown algae and filamentous red algae released in March, pelagic duration 15 days | Hard bottom | 1 | | |
| Connectivity HB community dominated by large brown algae and filamentous red algae released in June, pelagic duration 15 days | Hard bottom | 1 | | |
| Connectivity HB fauna community released in March, pelagic duration 45 days | Hard bottom | 1 | | |
| Connectivity HB type fauna community released in March, pelagic duration 15 days | Hard bottom | 1 | | |
| Connectivity HB type fauna community released in March, pelagic duration 45 days | Hard bottom | 1 | | |
| Harbour seal (Wadden Sea) | Pelagic & Fish | 1 | | |

| | | | | |
|--|----------------|-------|-------|-------|
| Estuarine front | Pelagic & Fish | 1 | | 1 |
| Minke whale | Pelagic & Fish | 1 | | |
| Whitebeaked dolphin | Pelagic & Fish | 1 | | |
| Harbour porpoise | Pelagic & Fish | 1 | | |
| Frontal areas in Skagerrak | Pelagic & Fish | 1 | | 1 |
| Tidal mixing front | Pelagic & Fish | 1 | | 1 |
| Demersal fish biomass | Pelagic & Fish | 1 | | |
| Pelagic fish biomass | Pelagic & Fish | 1 | | |
| Fish species richness | Pelagic & Fish | 1 | | |
| Primary productivity | Pelagic & Fish | 1 | | |
| AIS | Cost | -7.4 | | -4.7 |
| Military areas | Cost | -1.5 | | -0.94 |
| Average sub surface abrasion from mobile bottom contacting fishing gears | Cost | -3.7 | -0.75 | -2.35 |
| Average surface abrasion from mobile bottom contacting fishing gears | Cost | -3.7 | -0.75 | -2.35 |
| Value beam trawl | Cost | -0.7 | -0.75 | -0.47 |
| Value Danish seine | Cost | -0.7 | -0.75 | -0.47 |
| Value long line | Cost | -0.7 | | -0.47 |
| Value otter trawl | Cost | -0.7 | -0.75 | -0.47 |
| Value pelagic trawl | Cost | -0.7 | | 0.47 |
| Value Scottish seine | Cost | -0.7 | -0.75 | -0.47 |
| Value set gillnets | Cost | -0.7 | | -0.47 |
| Value set longline | Cost | -0.7 | | -0.47 |
| Value unknown gear | Cost | -0.7 | | -0.47 |
| Value traps | Cost | -0.7 | | -0.47 |
| Sediment extraction potential | Cost | -0.7 | -0.75 | -0.47 |
| Sediment extraction licensed | Excluded | Excl. | Excl. | Excl. |
| Offshore wind power planned | Excluded | Excl. | Excl. | Excl. |
| Offshore wind power existing | Excluded | Excl. | Excl. | Excl. |
| Oil & Gas | Excluded | Excl. | Excl. | Excl. |
| Pipeline & cables | Excluded | Excl. | Excl. | Excl. |

9.4.2 Theme 1a

9.4.2.1 Impacts and economic interests

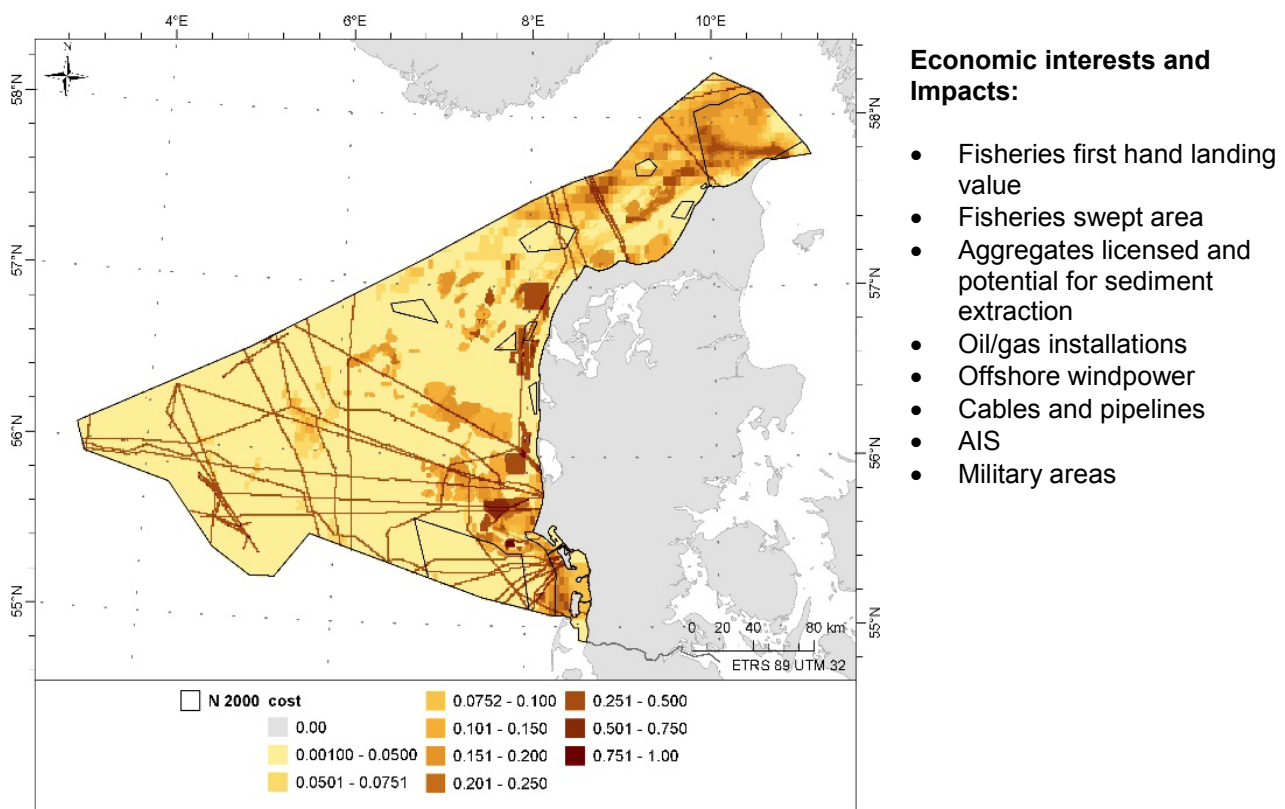
In the analysis area, there is very little difference between the mapped human activities that can be seen as impact and those that can be seen as economically valuable. Impact distances were not included. Oil and gas installations were e.g. only available as point data and are included as presence in one 1 km² grid cell. This is in accordance with the monitoring, where impact on benthos is limited to a distance between 250 and 500 m from the platforms. In this calculation also those human activities that lead to exclusion in the modelling were included in the impacts and economic interests (Figure 54).

To identify the impacts and economic interests, the fishery first hand landing values were summed up before normalization as well as the two area swept ratios. Cables and pipelines were combined into one presence – absence layer. The aggregates were combined into one layer, giving the highest value to the current production areas, a medium value to reserved common areas and the lowest value to potential areas.

After normalization, the layers were combined as follows:

Economic interests and Impacts = Pipeline&Cable+Offshore Wind power+ Oil&Gas installation+Aggregates+Swept Area Ratio*0.5+Fishery Value*0.5+AIS+Military Areas*0.2

The map combining all human activities was made to show areas with high activities. In the model, the value given to an area that is excluded anyway is not relevant.



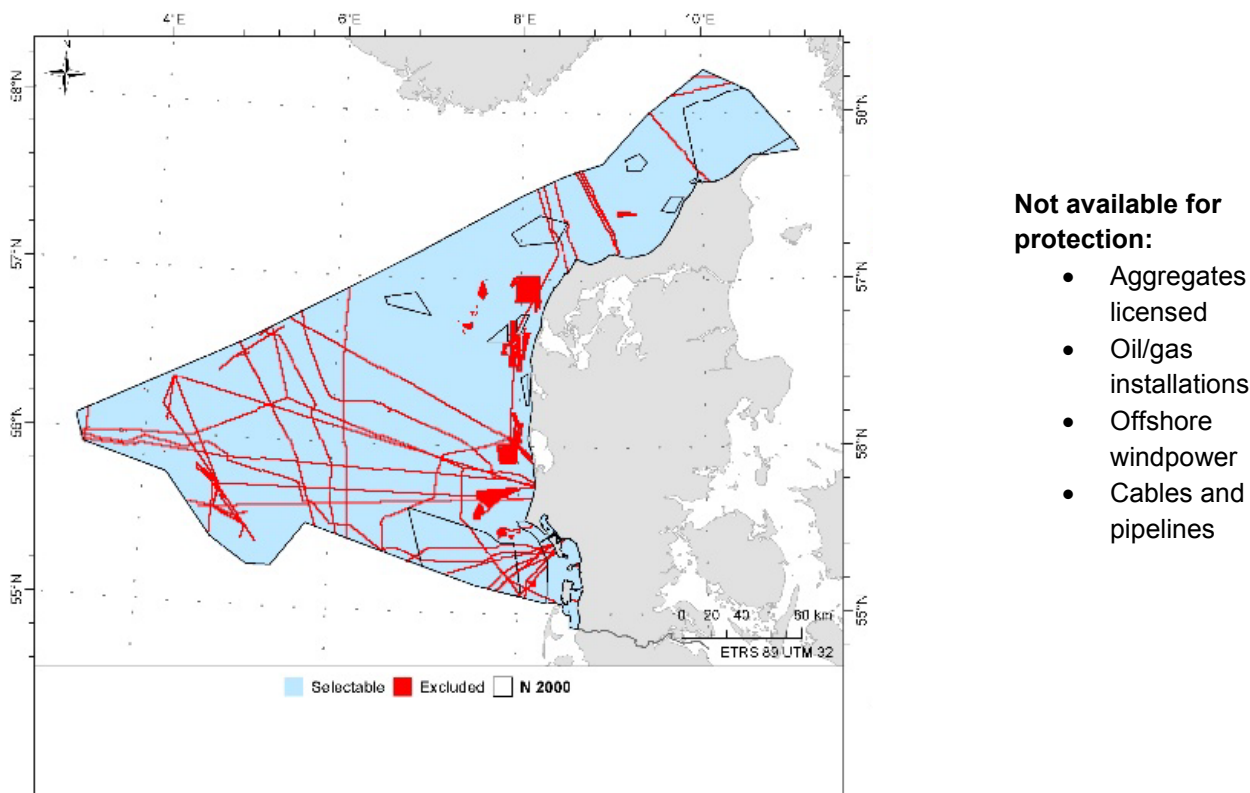


Figure 54 Impacts, economic interests and areas not available for protection for theme 3 MSFD in the North Sea.

9.4.2.2 Zonation results

The biodiversity features included in the theme 1a analysis are listed in Table 2. Zonation identified valuable areas for conservation in the south eastern most part of the Danish EEZ. Also a larger region of high conservation value is identified in the western most parts. Areas with hard bottom communities clearly also comes through as important areas (Figure 55). The performance curves shows that the spatially restricted features are well covered already at low levels of protection, while wide spread features as frontal areas and fish have a smaller proportion protected simply due to the wide coverage.

However, most features have at least a proportion distribution level remaining close to the proportion of the seascape under protection. If 20% of the seascape is protected and 20% of the species are covered a target of 20% is reached (Figure 57). When adding economic interest, the Skagerrak area becomes clearly less suitable for conservation due to intense fishing activities. Also, the important area in the southeast is shifted more offshore due to competing interests

Figure 59. While the area in the westernmost parts are more similar to the results based only on biodiversity features. The impact of the cost are also visible in the performance curves, indicating that slightly larger areas are required for protecting the same proportion as when the economic interest are not considered (Figure 58). The priority ranking maps can be compared against the maps of individual features and cost layers (listed in Table 2) and thereby it is possible to evaluate how the patterns of the different features/layers are represented in the final priority ranking map. The performance curves can further be used for a quantitative assessment of the representation of each biodiversity feature under a range of percentage protected (of the whole seascape).

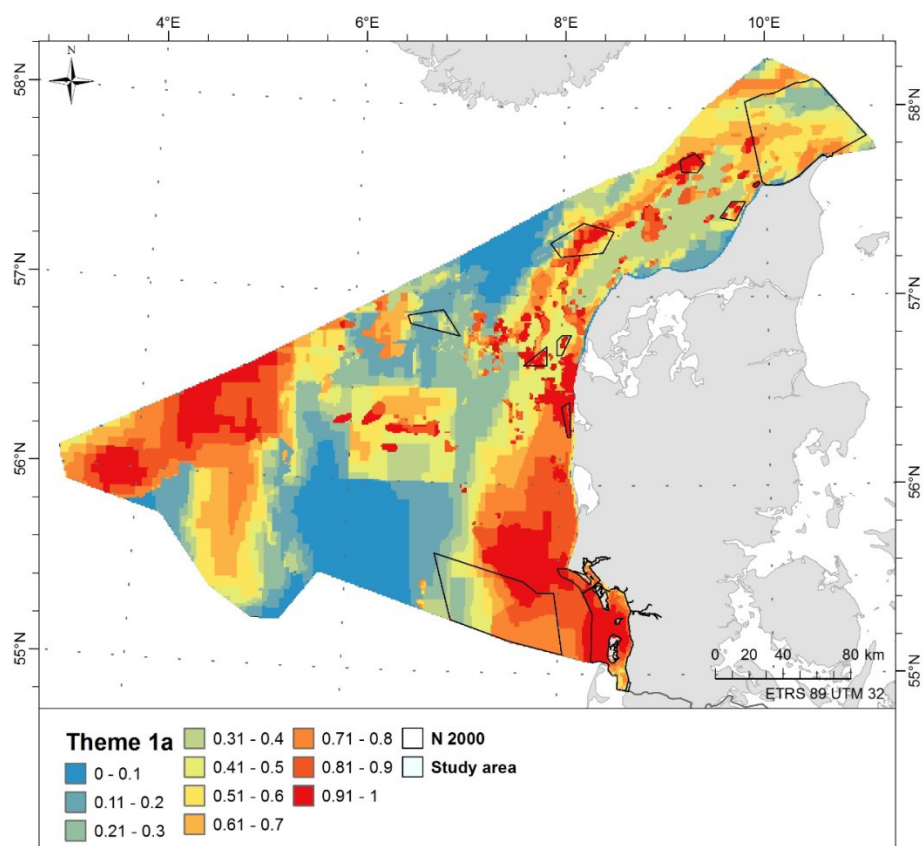


Figure 55 Zonation priority ranking map for theme 1A in the North Sea (colours) and existing Natura 2000 sites (black lines). The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

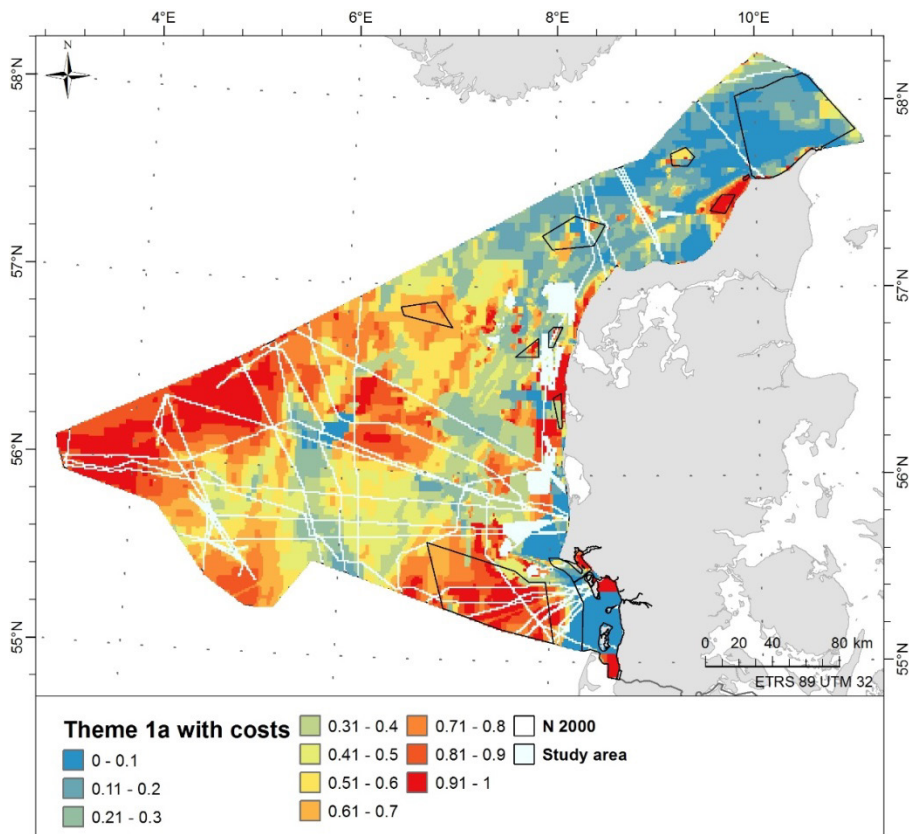


Figure 56 Zonation priority ranking map (colours) for theme 1a in the North Sea, when cost and exclusions are accounted for. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%. Exclusion areas are indicated in white colour and existing Natura 2000 sites are indicated with black lines. Data are a combination of beam trawl, pelagic trawl and surface subsurface area swept.

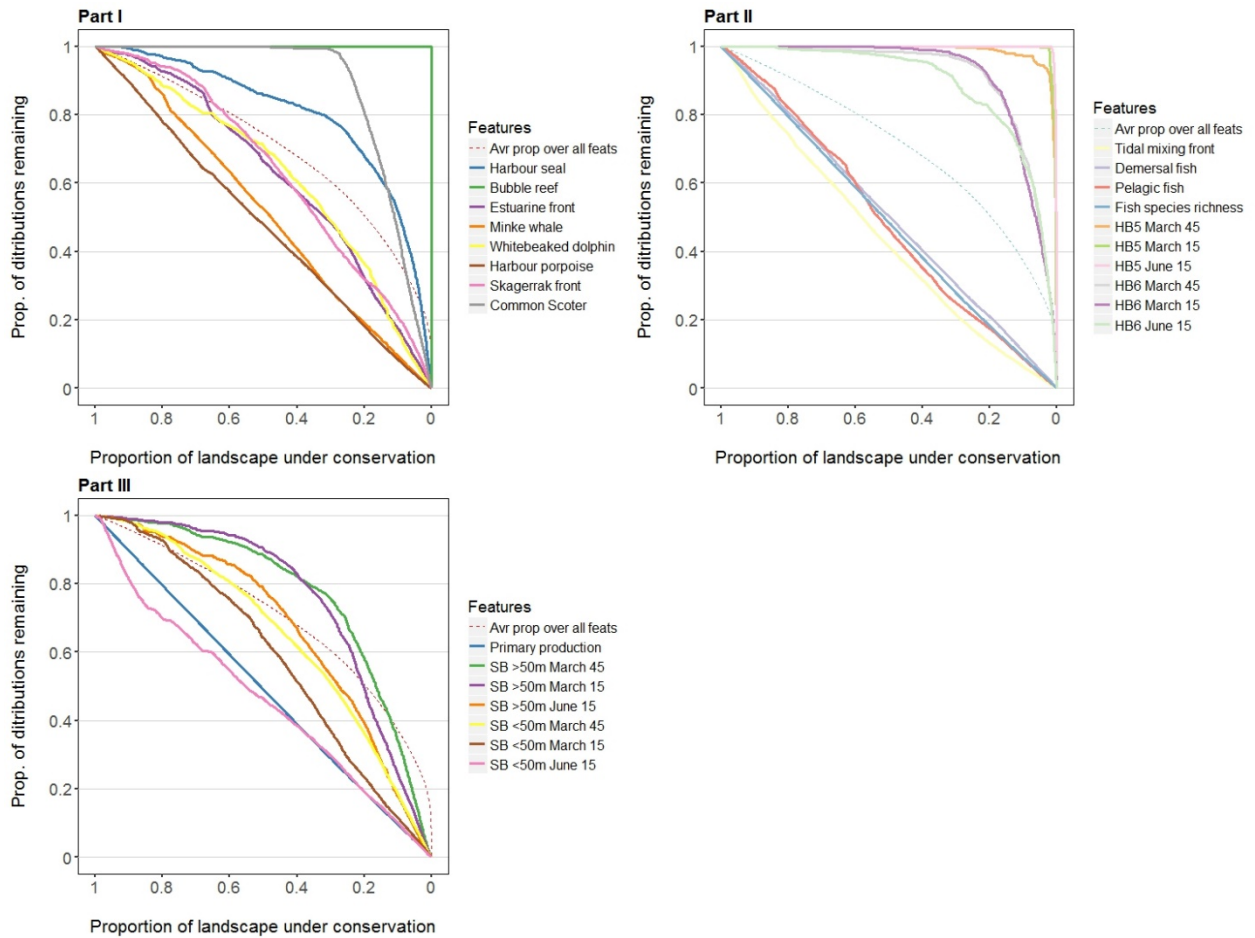


Figure 57 Zonation performance curves for theme 1a in the North Sea, shown in three graphs, each line depict one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

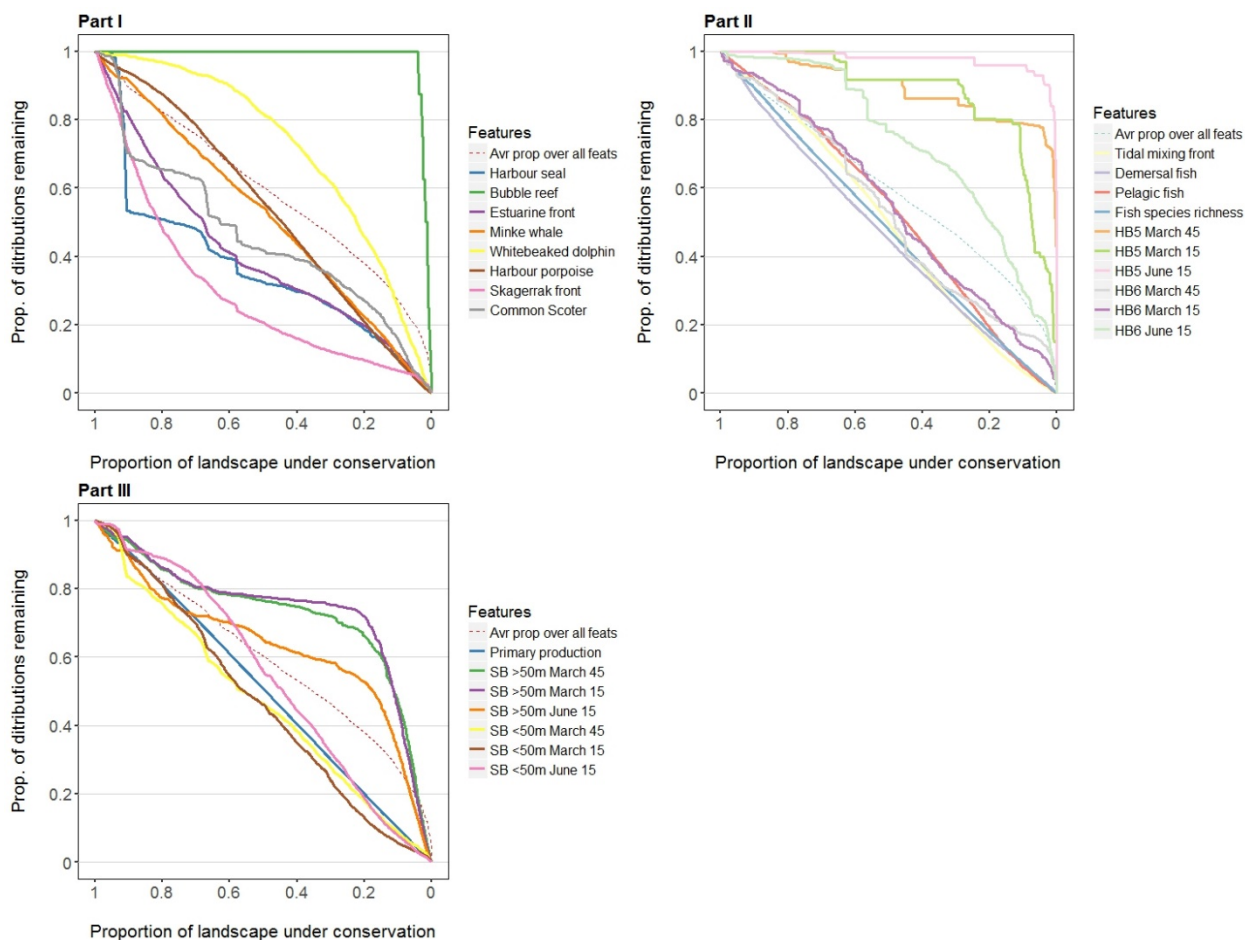


Figure 58 Zonation performance curves for theme 1a including costs and exclusions in the North Sea, shown in 3 graphs. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

9.4.2.3 Marxan results

In Marxan the same ecosystem components and costs were used as in the Zonation model runs. From an ecological point of view, the ecosystem components are not weighted, i.e. applying the targets 5 %, 10% and 20% to all of them. From the input data and the performance curves (Figure 57 and Figure 58) it is clear that this would mean that the pelagic environment would be dominating the selection, because the ecosystem components in this group on an average are more wide-spread than many of the benthic components. It was therefore decided to lower the targets for primary production, the fronts and the fish data to half of the respective target, i.e. to 2.5% instead of 5%, 5% instead of 10% and 10% instead of 20% scenario.

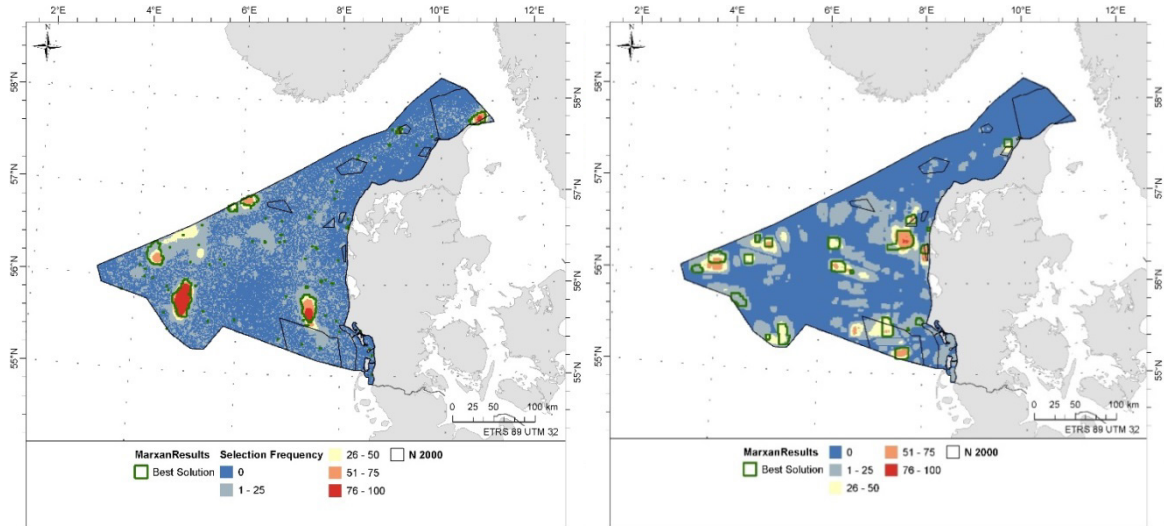
To reduce the influence of these layers additionally, the settings in Marxan were changed in a way that Marxan is less strict about reaching the targets for these layers. If the targets are reached, i.e. as a minimum the chosen percentage per ecosystem component is selected. It depends on the balance between ecosystem features and costs. A penalty factor is steering per ecosystem feature if it is more important to try to select more of this ecosystem feature (and thereby cause higher costs) or if it is OK not to reach the target for this feature. While lowering the targets for at ecosystem component reduces its influence in general, lowering the penalty for not reaching the target on the other hand has only influence in case of conflicts.

In contrast to the presentation in Zonation, Marxan calculates several possible solutions for the same scenario, which are described as selection frequency (defined in chapter 9.3). Even with these lowered targets, it can be seen that the pelagic components have quite a strong influence, dragging e.g. selection in the important area around Horns Rev – Fanø Bugt and Wadden Sea into the deeper part. The reason for this is the low differences in some ecosystem components and the data quality for others.

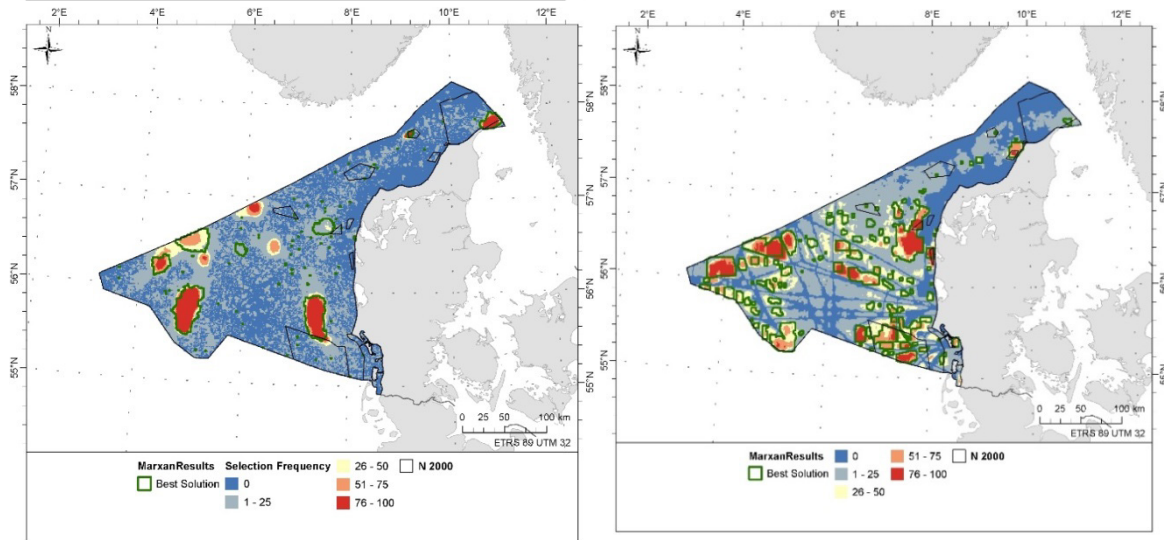
When costs are taken into consideration, the Marxan results are more similar to the Zonation results, because the degrees of freedom for selection are reduced.

In this scenario the selected area for the best solution does not increase when introducing costs for target 20%, the selected area is basically the same with 10,812 km² and without costs (10,940 km²). The reason for this is, that with the chosen balance of the penalty for not reaching the targets and the costs is in favour of avoiding costs, in some runs the targets are not reached, which also include the best solution with costs. Without costs, more than 97% of the target was in all cases reached, whereas with costs, only 62.5% of the targets were reached in many solutions.

5%



10%



20%

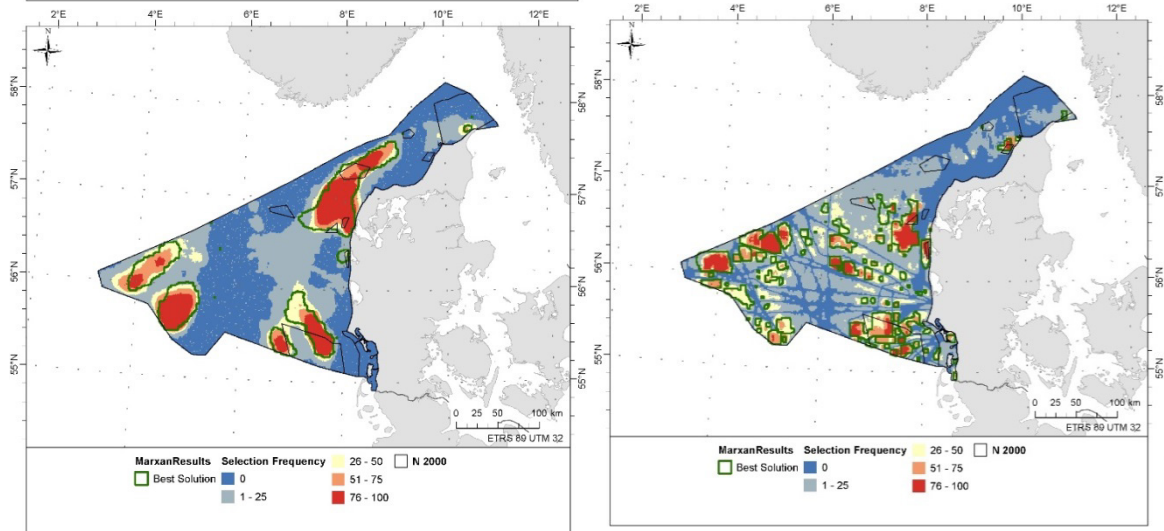


Figure 59 Suitable new sites with protection targets 5 % (top), 10% (middle) and 20% (bottom) for the features of theme 1a in the North Sea, on the left without accounting for the costs and exclusions, on the right when costs and exclusions are accounted for. Title colour scale shows how often a grid cell is included in the solutions. Red is nearly in all solutions. The low values in only very few solutions.

9.4.3 Theme 2 – Soft Bottom

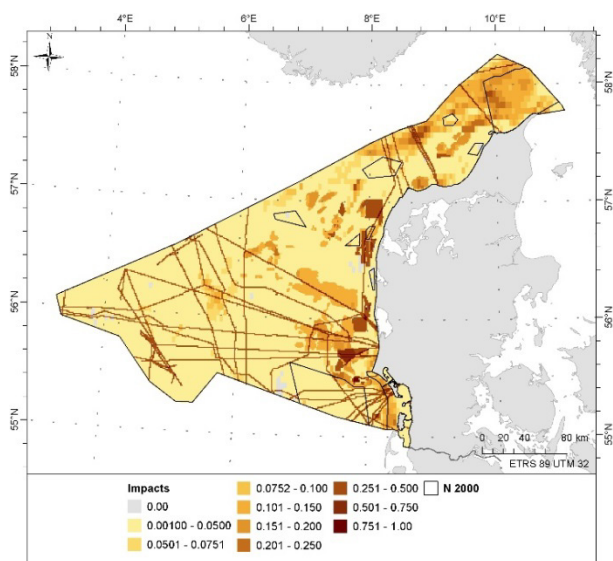
9.4.3.1 Impacts and economic interests

In the area analysed, there is very little difference between distribution of the mapped human activities that have impact on soft bottoms and the distribution of economic interests. Fisheries first hand landing value of active gears with bottom contact include otter trawls, Danish and Scottish seine and beam trawl.

To identify the impacts and economic interests that are of importance for the fisheries on benthic habitats, the relevant fishery first hand landing values (Beam Trawl, Danish seine, otter trawl, Scottish seine) were summed up before normalization as well as the two area swept ratios. Cables and pipelines were combined into one presence – absence layer. The aggregates are combined into one layer, giving the highest value to the current production areas, a medium value to reserved common areas and the lowest value to potential areas. Military operations were not assumed to interfere with bottom trawling or cause reduced benthic quality and military areas were therefore not included as a separate layer.

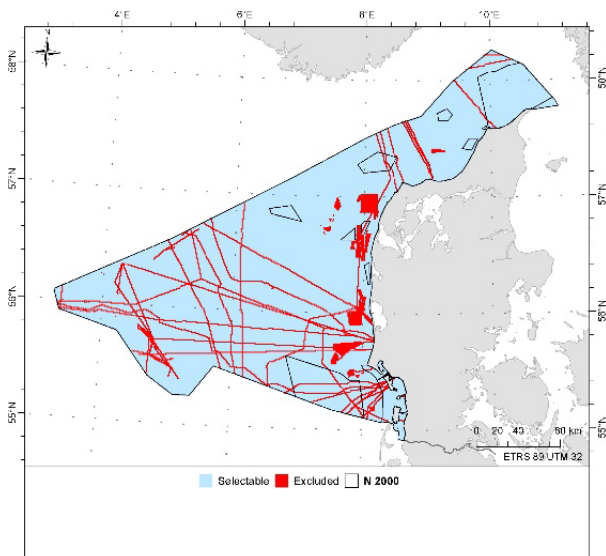
After normalization the layers were combined as follows:

Economic interests and Impacts = Pipeline Cable+Offshore Windpower+ Oil/Gas installation+Aggregates +Swept Area Ratio*0.5+Fishery Value*0.5



Economic interests and impacts:

- Fisheries first hand landing value of active gears with bottom contact
- Fisheries swept area
- Aggregates licensed and potential for sediment extraction
- Oil/gas installations
- Offshore windpower
- Cables and pipelines



Not available for Protection:

- Aggregates licensed
- Oil/gas installations
- Offshore windpower
- Cables and pipelines

Figure 60 Impacts, economic interests and areas not available for protection for theme 2 soft bottoms in the North Sea.

9.4.3.2 Zonation results

The variables selected in theme 2 are listed in Table 2, and include only the soft bottom connectivity layers. The areas identified as important for conservation by zonation is similar to the areas selected in theme 1, areas to the southeast and the westernmost part of the Danish EEZ (Figure 61, Figure 63). The reason for this similarity is because the same layers included in theme 2 are also included in theme 2, and these features (included in both themes) are relatively widely spread and therefore also influential when other layers are included. Another reason is that the same areas are important for many biodiversity features. When economic interests are included there is a similar spatial shift in high priority areas as in theme 1a (Figure 60). The proportion of the feature-specific distributions at different levels of protection is lower than when not considering conflicting interests (Figure 63 and Figure 64). The soft bottom connectivity layer <50m released in June, for example, is not achieving “the targets” of 5%, 10% and 20%, although not that far from the targets (Figure 64).

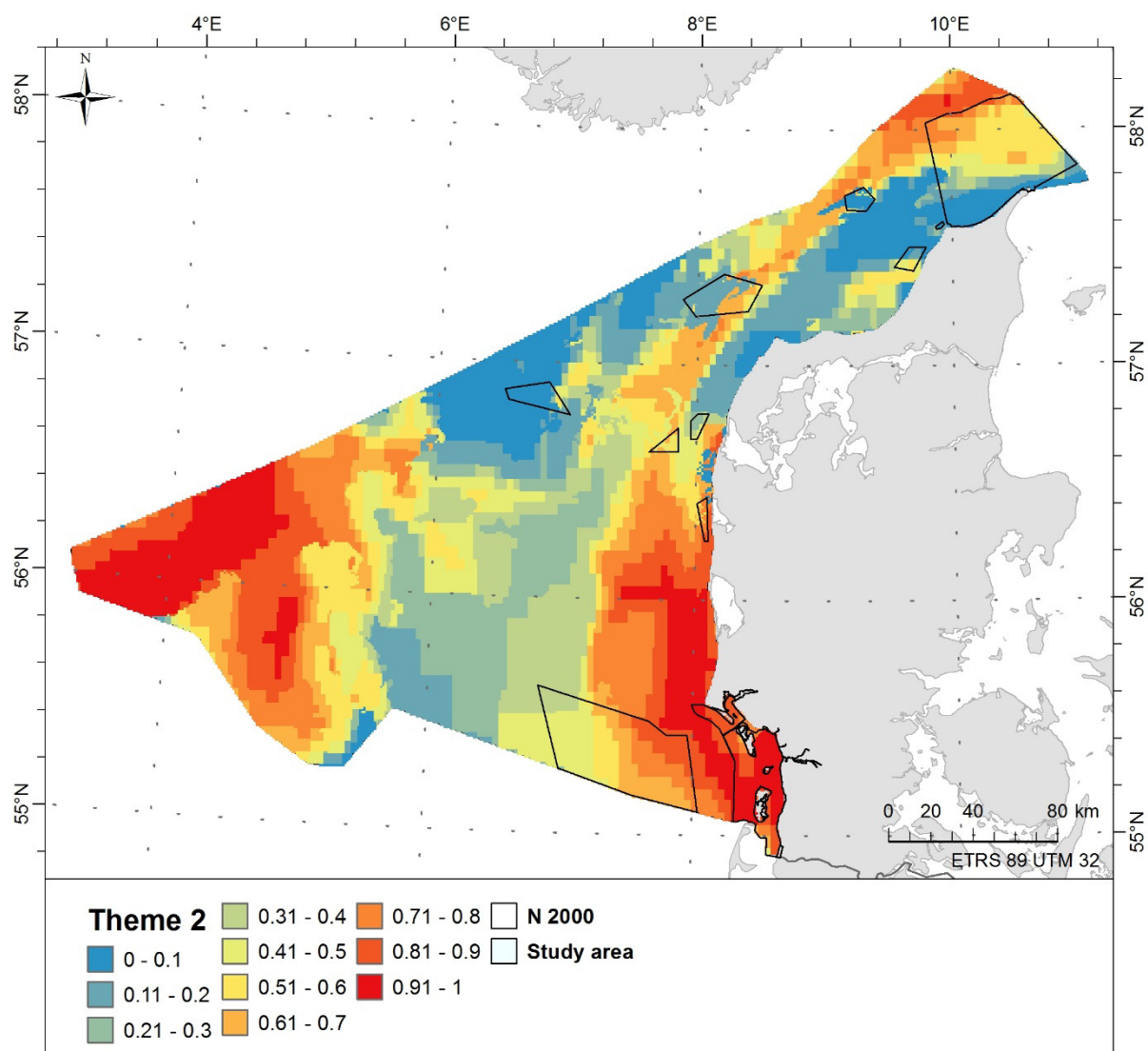


Figure 61 Zonation priority ranking map for theme 2 in the North Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10% (the indicated Study area in the legend is the whole Danish EEZ).

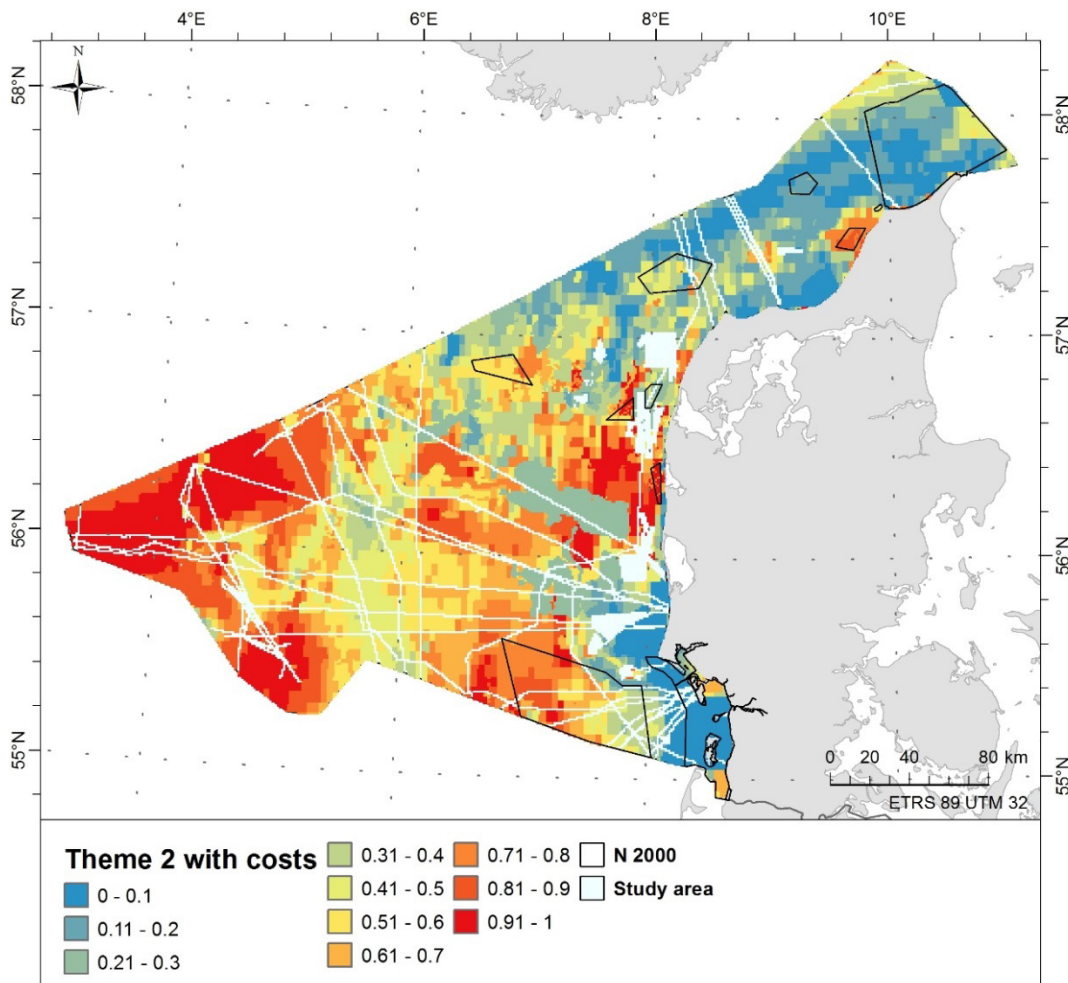


Figure 62 Zonation priority ranking map for theme 2 when costs and exclusions are included in the North Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

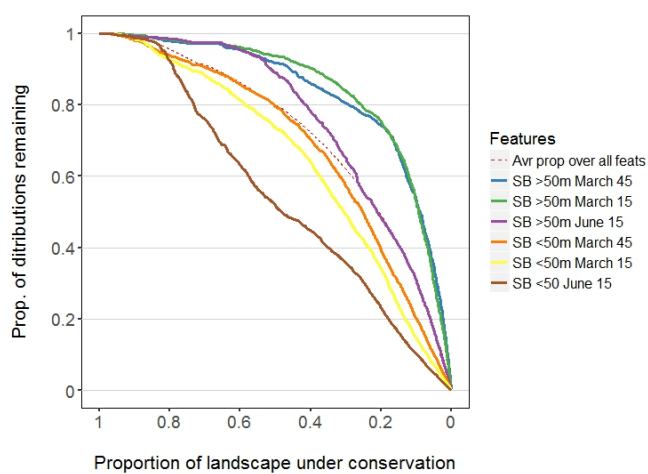


Figure 63 Zonation performance curves for theme 2 in the North Sea. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

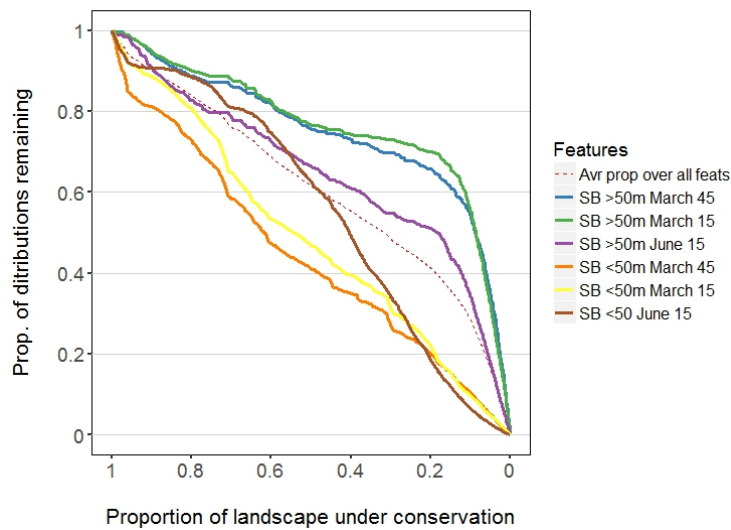


Figure 64 Zonation performance curves for theme 2 in the North Sea. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

9.4.3.3 Marxan results

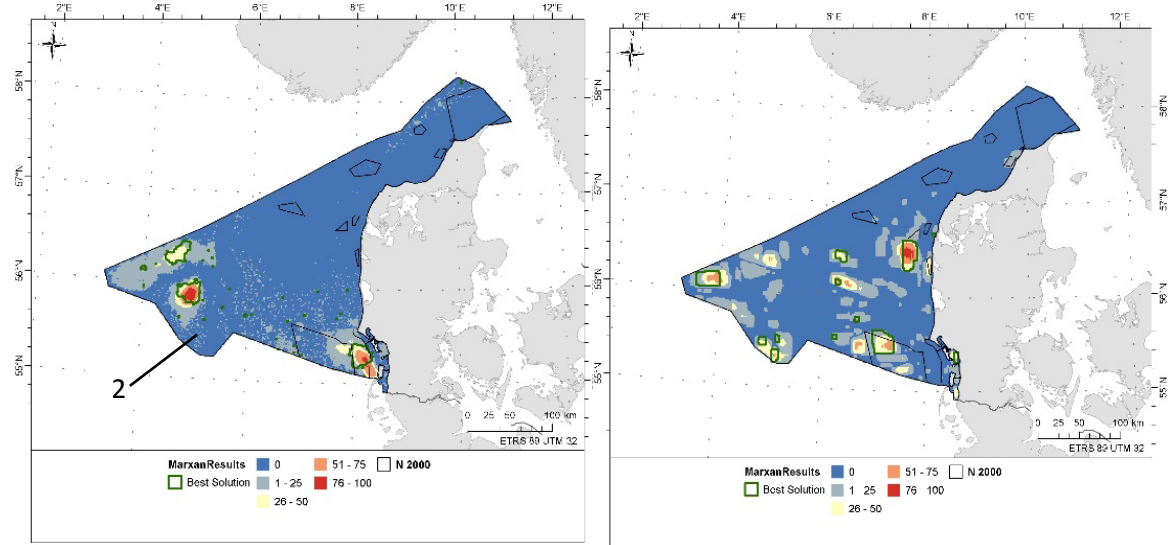
In both the new site suggestions with and without including conflicts (Figure 65), a high selection rate is seen in the south, perhaps driven by the “sourciness” represented in the connectivity layer. In the North Sea with a current direction dominantly northwards, the southernmost areas may be best suitable acting as sources for the downstream (northern) areas.

Without conflicts it is possible to designate two areas for the shallow soft bottom, whereas the suitable area for the deep soft bottom type is very limited. The suggestion solely based on connectivity does not provide replication.

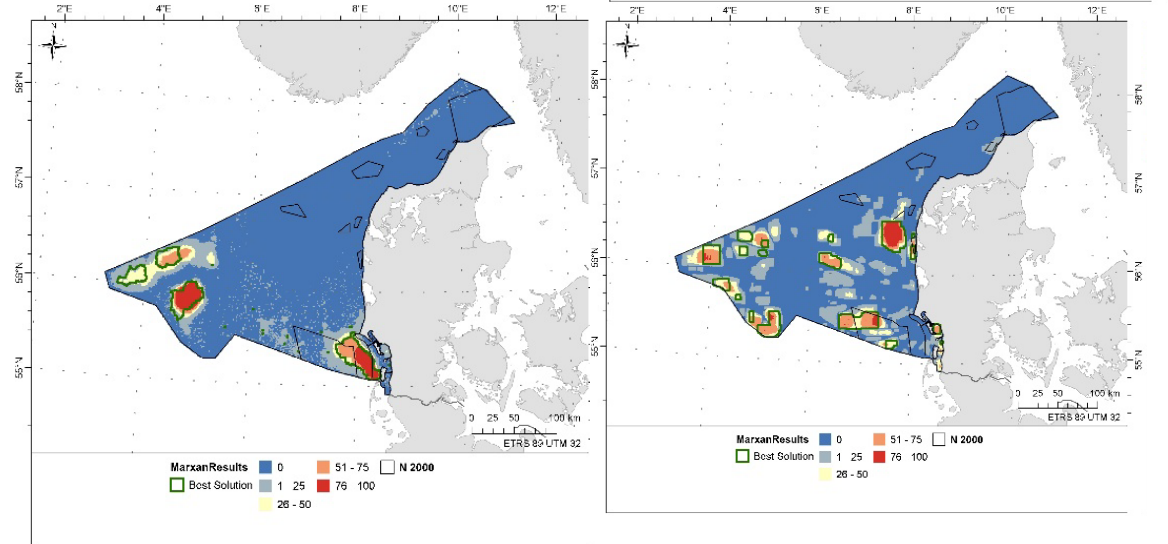
When avoiding conflicts with human uses, the suggested sites extends northwards to around the middle of the analysis area. Especially the important area at Horns Rev – Fanø Vest and an offshore area (labelled 2 in Figure 65) are overlapping with many conflicts and therefore not selected in this run. Instead an area south of Thyborøn Stenvolde is the most selected area in all three scenarios.

The conflicts are pushing the selection into less optimal areas. To reach e.g. 20 % of the protection target (which is not the area but 20% of the values of the ecosystem components) the area increased from 6,510 km² to 9,650 km², i.e. an increase of 150%.

5%



10%



20%

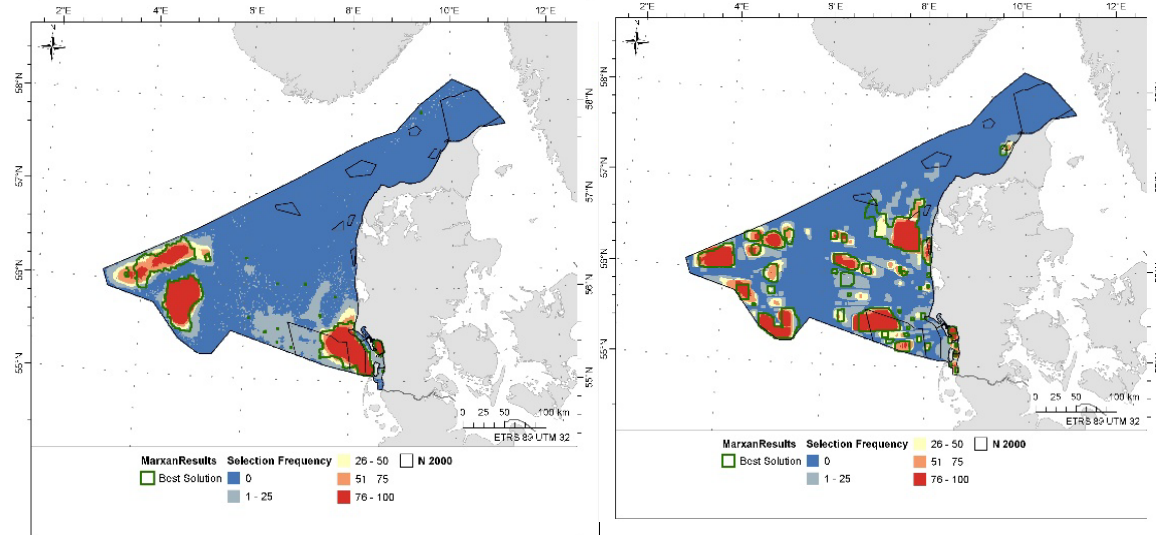


Figure 65 Suitable new sites with protection targets 5 % (top), 10% (middle) and 20% (bottom) for the features of theme 2 in the North Sea, on the left without accounting for the costs and exclusions, on the right when cost and exclusions are accounted for.

9.4.4 Theme 3 MSFD

9.4.4.1 Impacts and economic interests

The impacts and economic interests are the same as for theme 1a, chapter 9.4.2.1.

9.4.4.2 Zonation results

Theme 3 resulted in similar patterns as the other two themes (Figure 66, Figure 68). Also, when costs were included (Figure 67, Figure 69).

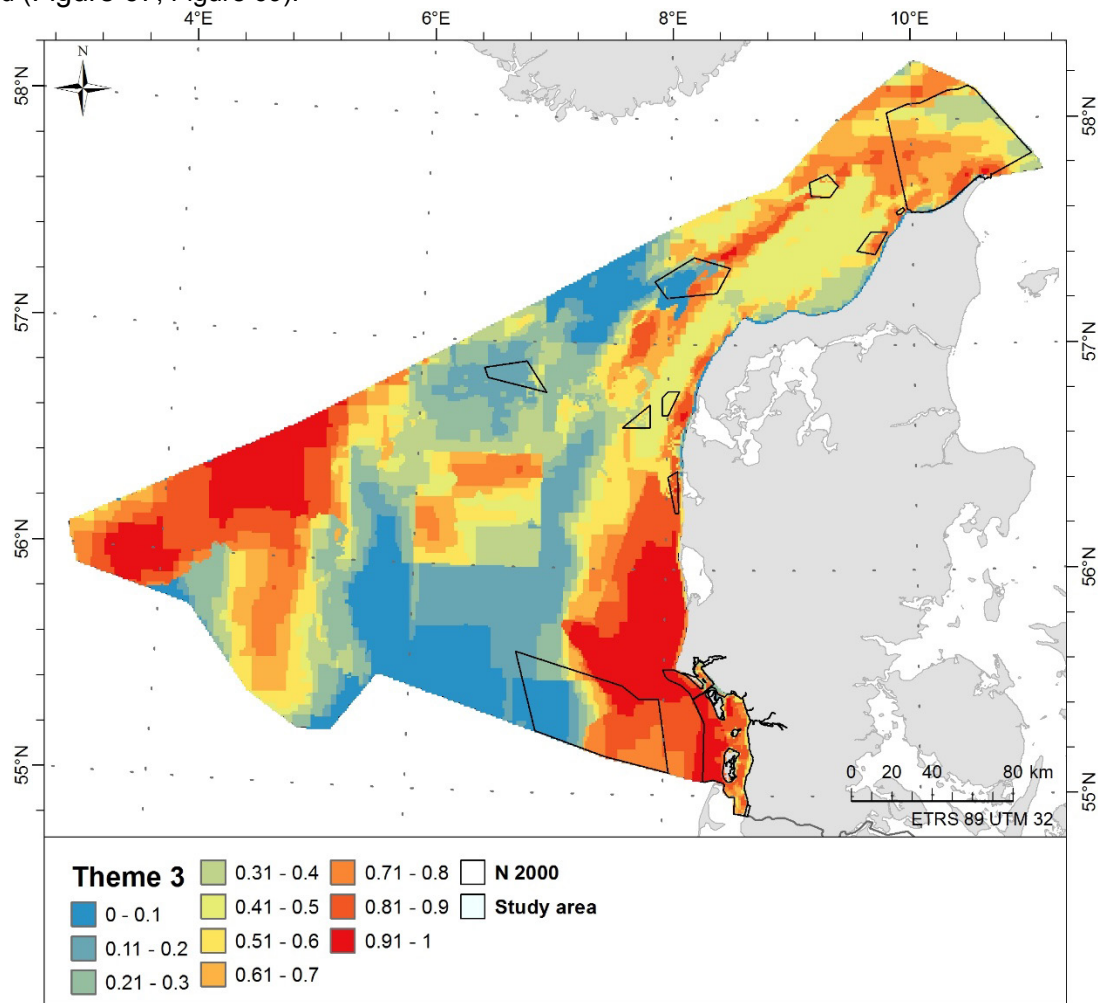


Figure 66 Zonation priority ranking map for theme 3 in the North Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10 % (the indicated Study area in the legend is the whole Danish EEZ).

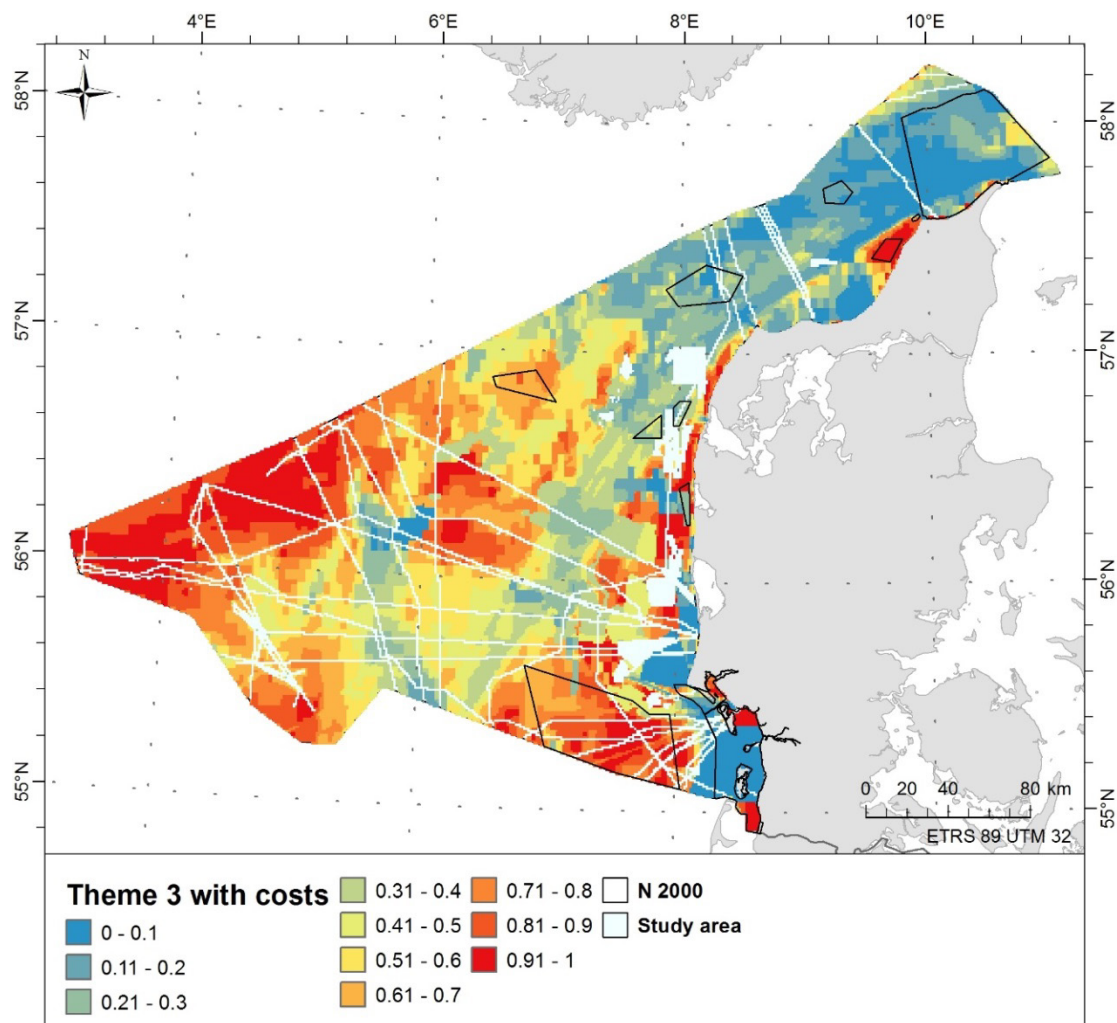


Figure 67 Zonation priority ranking map for theme 3 including costs and exclusions in the North Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10% (the indicated Study area in the legend is the whole Danish EEZ).

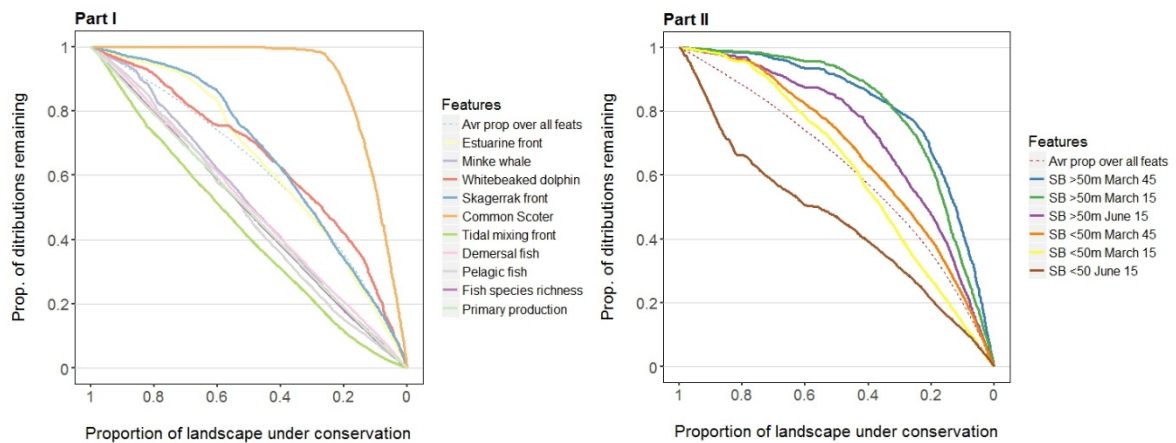


Figure 68 Zonation performance curves for theme 3 in the North Sea, shown in 2 graphs. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

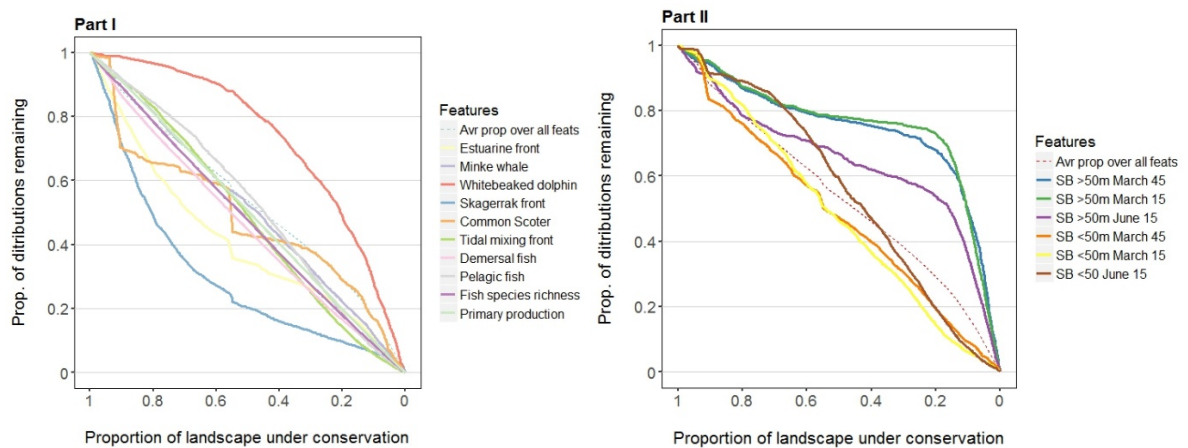
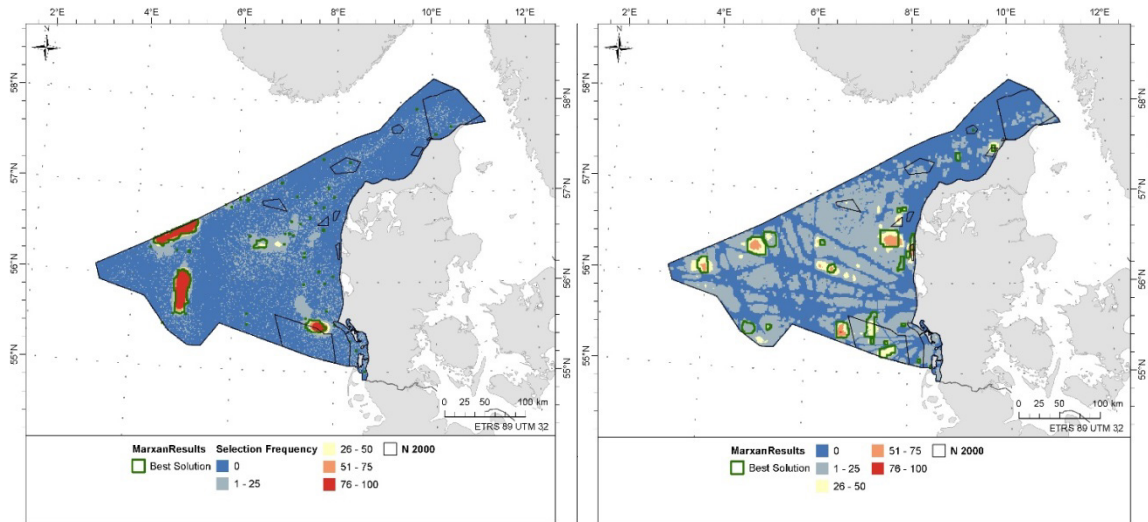


Figure 69 Zonation performance curves for theme 3 including costs and exclusions in the North Sea, shown in 2 graphs. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

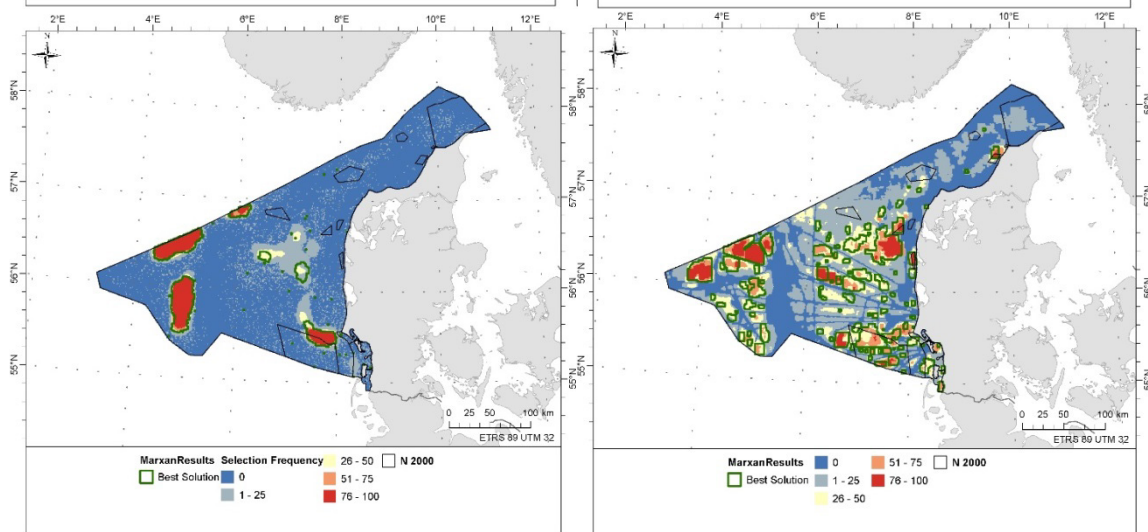
9.4.4.3 Marxan results

Similar to theme 1a, the targets and penalty factors were reduced for primary production, for hydrographic fronts and for fish data. Introducing costs for the target 20% means that the selected area increases to 120% of the selected area without costs, indicating that the solution is less optimal for the ecosystem components. With the chosen settings in this theme, the targets can be reached even for the ecosystem components with lower penalty factor.

5%



10%



20%

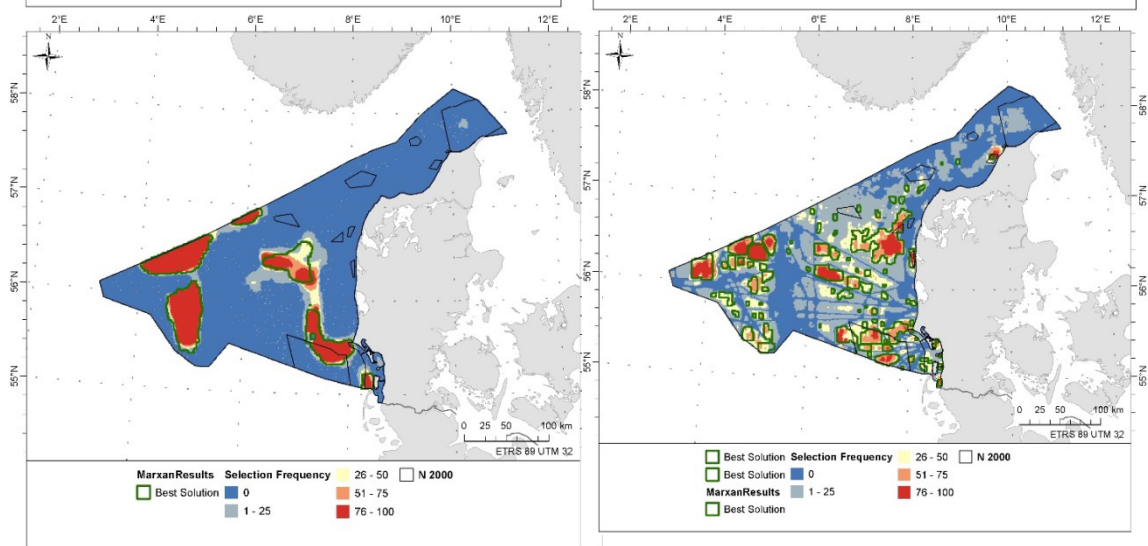


Figure 70 Suitable new sites with protection targets 5 % (top), 10% (middle) and 20% (bottom) for the features of theme 3 in the North Sea, on the left without accounting for the costs and exclusions, on the right when cost and exclusions are accounted for.

9.5 Baltic Sea results of Zonation and Marxan

9.5.1 Area specific model input

The same themes as in the North Sea were simulated for the Baltic Sea area. For this area we also modelled hotspots in a theme 1b, as we had surrogate layers for soft bottoms, hard bottom and pelagic features. For theme 1a we also tested to weight the biodiversity features in a way that achieved equal weight on soft bottom, hard bottom and pelagic features.

All input variables, biodiversity features as well as economic and pressure variables are listed in Table 3.

For theme 1a we also tested to weight the biodiversity features in a way that achieved equal weight on soft bottom, hard bottom and pelagic features.

Ecosystem components:

- Soft bottom invertebrate communities 1, 2 and 3 based on biomass as described in part 1
- Primary production, frontal index, hard bottom and marine mammals (harbour porpoise and grey seal) as described in part 1.
- For birds a modelled data layer was taken that covers the complete Danish waters around Bornholm and that is based on data in figure 52 and 53 and international data from the SOWBAS project (<http://www.diva-portal.org/smash/get/diva2:701707/FULLTEXT01.pdf>). Fish were only grouped for pelagic and demersal biomass and species richness.
- Additional filter feeder and deposit feeder indices.

Instead of using the connectivity functions of Zonation and Marxan, the connectivity was included as sourciness layers from the IBMLib model, similar to the approach suggested by Magris *et al.* (2015). Sourciness was calculated for the benthic hard bottom and for the soft bottom communities without oxygen deficit. However, the coverage of the IBMLib has gaps in the coastal area which means that full coverage cannot be achieved for the coastal hard bottom communities. Thus, connectivity data for all soft bottom communities, while for the hard bottom communities only the areas dominated by *Mytilus* were included in the models.

Human activities:

- Sediment extraction, offshore wind power, AIS density as shipping intensity, cables and pipelines, WW2 chemical munition dumpsites and military interests as described in chapter 0.
- For fisheries the first hand value of landings and the swept area ratios were used
- Poland is objecting to the current EEZ border and is claiming an area up to the territorial border. It was decided to exclude this area from the suggested sites.

As for the North Sea, efforts were taken to ensure a comparable effect of each feature in the respective models. The weighting of the ecosystem components takes into account the importance, data quality and the dominance of some features. These effects were examined in scenario 1a. The chosen weights for Zonation are listed in Table 2. For Marxan, targets for some layers were reduced in Scenario 1a and 3 as is described later in this chapter.

To achieve a similar weighing of different sectors, weights were set for the normalized cost layers in Zonation (Table 3). For Marxan and the identification of economically important areas, a slightly more complex approach was taken.

Table 3 Layers included in the different model runs in the Baltic Sea, themes 1a, 1b, 2 and 3. SB = soft bottom and HB =hard bottom, connectivity: 3L= released in March 45 days, 3S= released in March 15 days and 6s= released in June 15 days. The zonation weight of each feature included in the specific theme (1a, 1b, 2 or 3), and the weights for the “grouped” 1A scenario is given in brackets.

| Layer description | Group | 1 a | 1 b | 2 | 3 |
|---|---------------|--------------|-----|------|------|
| SB soft bottom biomass based 1 Saduria entomon... | Soft bottom | 1 (1) | | 1 | 1 |
| SB soft bottom biomass based 2 Hediste diversicolor | Soft bottom | 1 (1) | | 1 | 1 |
| SB soft bottom biomass based 3 Diastylis... | Soft bottom | 1 (1) | | 1 | 1 |
| Deposit feeder index | Soft bottom | 1(1) | 1 | 1 | 1 |
| Filter feeder index | Hard bottom | 1 (1.5) | 1 | 1 | 1 |
| Front index | Pelagic | 1 (1) | 1 | | 1 |
| HB1 Fucus belt community | Hard bottom | 1 (1.5) | | | |
| HB2 Furcellaria and mytilus community | Hard bottom | 1 (1.5) | | | |
| HB3 Mytilus dominated community | Hard bottom | 1 (1.5) | | | |
| Grey seals | Pelagic | 1 (1.9) | | | |
| Photosynthetic available radiation (PAR) | Hard bottom | 1 (1.5) | 1 | | |
| Harbour porpoise summer | Pelagic | 1 (1.9) | | | |
| Harbour porpoise winter | Pelagic | 1 (1.9) | | | |
| Primary production | Pelagic | 1 (1.9) | 1 | | 1 |
| Long-tailed duck density | Hard bottom | 1 (1.5) | | | 1 |
| Demersal fish biomass | Pelagic | 1 (1.9) | | | 1 |
| Fish species richness | Pelagic | 1 (1.9) | | | 1 |
| Pelagic fish biomass | Pelagic | 1 (1.9) | | | 1 |
| HB type 3 connectivity 3L | Hard bottom | 1 (1.5) | | | |
| HB type 3 connectivity 3S | Hard bottom | 1 (1.5) | | | |
| HB type 3 connectivity 6S | Hard bottom | 1 (1.5) | | | |
| SB type 1 connectivity 3L | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 1 connectivity 3S | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 1 connectivity 6S | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 2 connectivity 3L | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 2 connectivity 3S | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 2 connectivity 6S | B Soft bottom | 1 (1) | | 1 | 1 |
| SB type 3 connectivity 3L | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 3 connectivity 3S | Soft bottom | 1 (1) | | 1 | 1 |
| SB type 3 connectivity 6S | Soft bottom | 1 (1) | | 1 | 1 |
| AIS from HELCOM | Cost | -8.3 (-10.8) | | | -5 |
| Sediment extraction potential | Cost | -1.7 (-2.2) | | -1.7 | -1 |
| Average sub surface | Cost | -4.2 (-5.4) | | -2.5 | -2.5 |

| | | | | | |
|--|----------|-------------|--|-------|-------|
| abrasion from mobile bottom contacting fishing gears | | | | | |
| Average surface abrasion from mobile bottom contacting fishing gears | Cost | -4.2 (-5.4) | | -2.5 | -2.5 |
| Value drifting long line | Cost | -1.2 (-1.5) | | | -1 |
| Value Danish seine | Cost | -1.2 (-1.5) | | -1.7 | -1 |
| Value otter trawl | Cost | -1.2 (-1.5) | | -1.7 | -1 |
| Value pelagic trawl | Cost | -1.2 (-1.5) | | | -1 |
| Value set gillnets | Cost | -1.2 (-1.5) | | | -1 |
| Value unknown gear | Cost | -1.2 (-1.5) | | | -1 |
| Dumped munition area | Cost | -1.7 (-2.2) | | -1.7 | -1 |
| Military area | Cost | -1.7 (-2.2) | | | -1 |
| Pipeline & cables | Excluded | Excl. | | Excl. | Excl. |
| OWF planned | Excluded | Excl. | | Excl. | Excl. |
| Sediment extraction licensed | Excluded | Excl. | | Excl. | Excl. |
| Polish claim (political) | Excluded | Excl. | | Excl. | Excl. |

9.5.2 Theme 1a

9.5.2.1 Impacts and economic interests

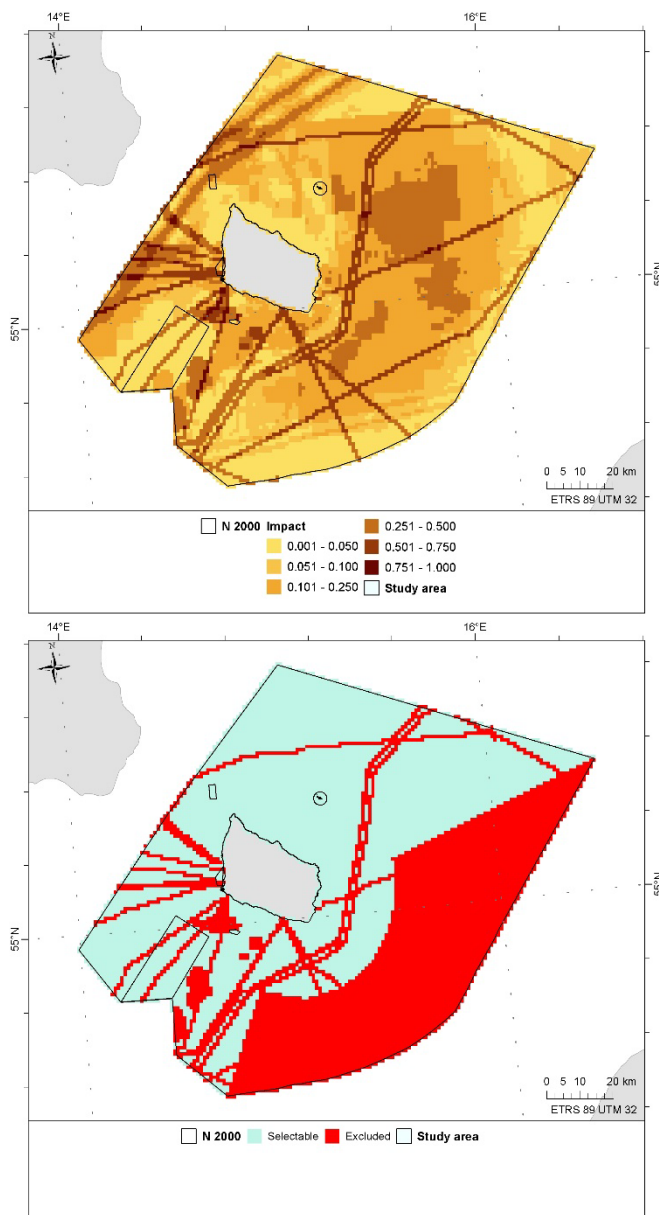
To identify the impacts and economic interests, the fishery first hand landing values were summed up before normalization as well as the two ratios for swept area . Cables and pipelines were combined into one presence – absence layer. The aggregates were combined into one layer, giving the highest value to the current production areas, a medium value to reserved common areas and the lowest value to potential areas.

After normalization the layers were combined as follows:

Economic interests and Impacts = Dumped Munition*0.2+Pipeline&Cable+Offshore

Windpower+Aggregates+Swept Area Ratio*0.5+Fishery Value*0.5+AIS+Military Areas*0.2

With the applied settings to weigh cables and pipelines equal to the other sectors, they influence the aggregated impacts and economic interests very much southwest of Bornholm. On the South-eastern part of Rønne Banke and Adler Grund high interests for sediment extractions and offshore wind power occurs, the fisheries effort is highest in Bornholm Basin and the most intensive ship traffic is going through Bornholms Gat. Additional to the human activities listed in Figure 71, it was decided to exclude the area of Polish claim of that area for modelling.



Economic interests and impacts:

- Fisheries first hand landing value
- Fisheries swept area
- Aggregates licensed and potential for sediment extraction
- Planned offshore windpower
- Cables and pipelines
- AIS
- Military areas (weight 0.2)
- Dumped munition area (weight 0.2)

Not available for protection:

- Pipeline & cables
- Offshore windpower planned
- Sediment extraction licensed
- Polish claim

Figure 71 Impacts, economic interests and areas not available for protection for theme 1a in the Baltic Sea.

9.5.2.2 Zonation results

The results by Zonation for theme 1a indicate that the areas southwest and south of Bornholm have the highest conservation values (Figure 72). The performance curves indicate that many of the features are well represented, if for example 20% of the landscape is protected. The proportion of the distribution remaining of the widely spread features are naturally lower than the more constrained features. And the fish is lower partly because of the coarse resolution (Figure 74). When the features were weighed by feature groups the changes in priority ranking was minor (Figure 75). The weighting was done to make each group of features more equally represented, and to assess how the weighting would affect the results. When also considering cost and exclusions, the results changed more, making the area north of Bornholm more valuable (Figure 76, Figure 78), while the change in weighting of the biodiversity features resulted in minor change (Figure 77, Figure 79).

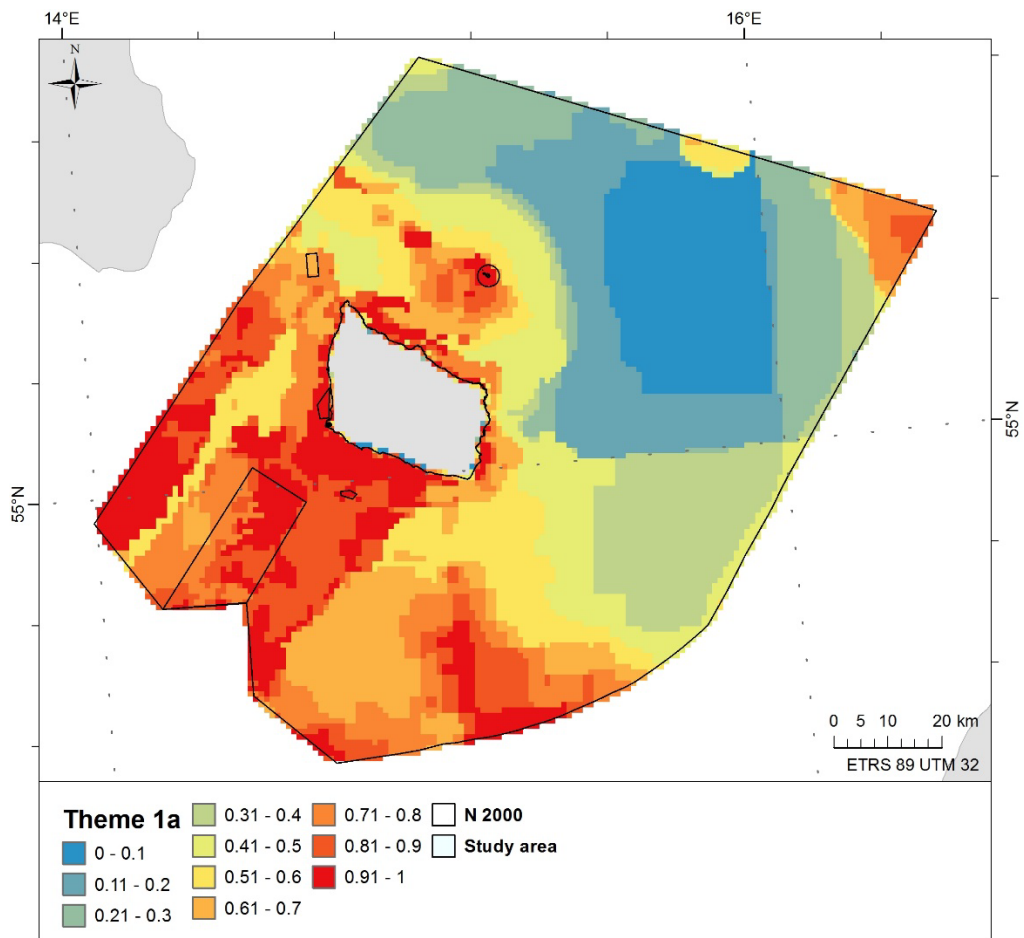


Figure 72 Zonation priority ranking map for theme 1A in the Baltic Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

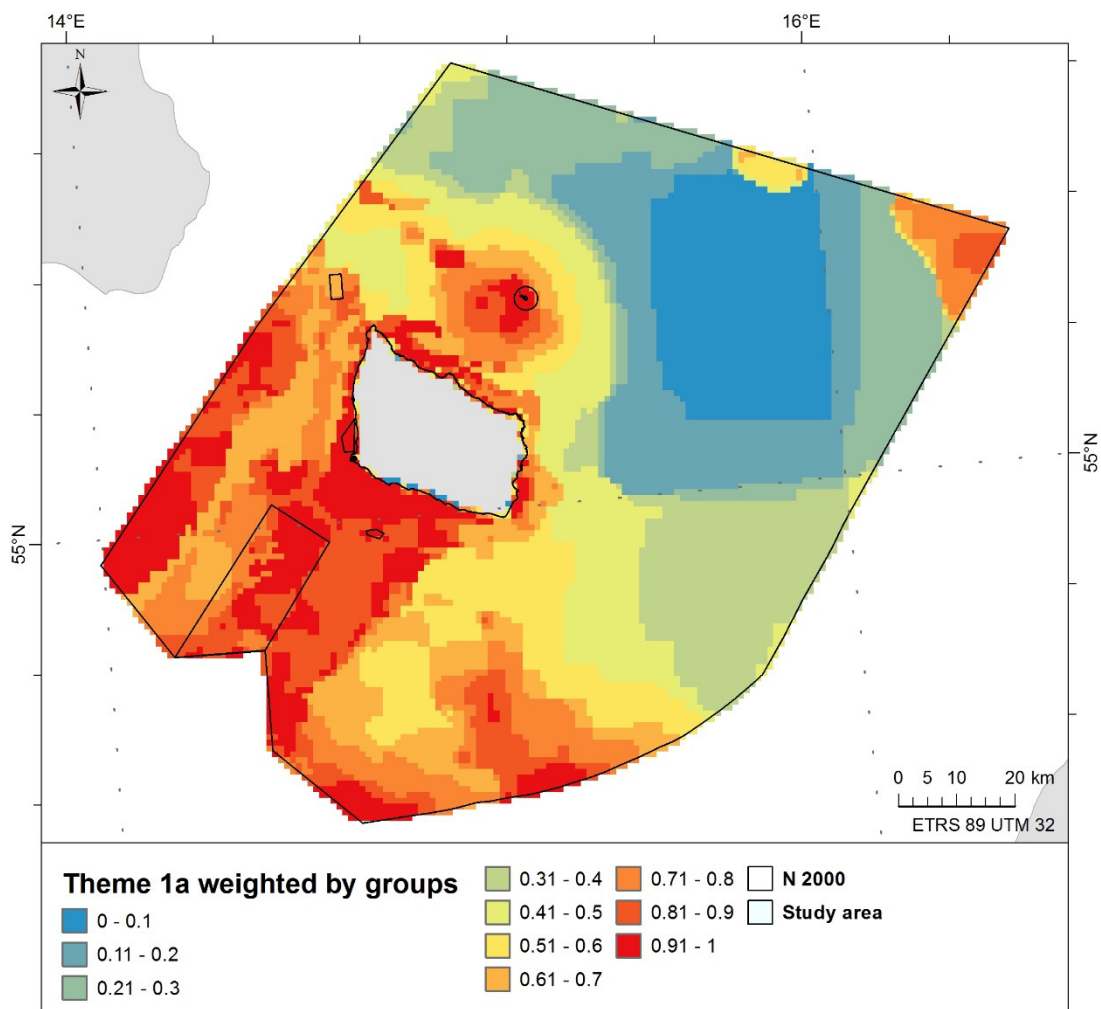


Figure 73 Zonation priority ranking map for theme 1A in the Baltic Sea. The biodiversity features are weighted so that soft bottom and hard bottom communities as well as pelagic features get the same weight. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

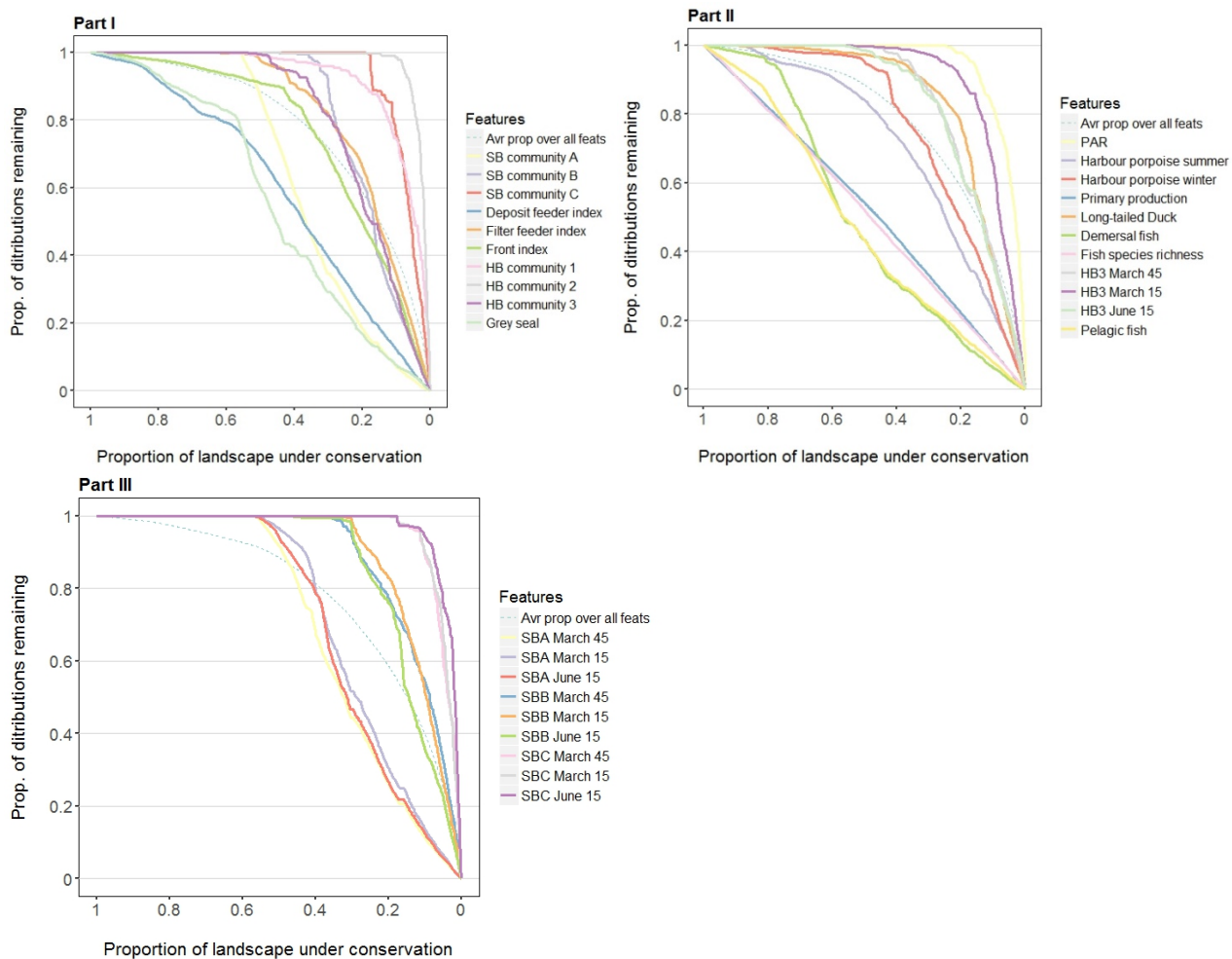


Figure 74 Zonation performance curves for theme 1a in the Baltic Sea, shown in 3 graphs. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

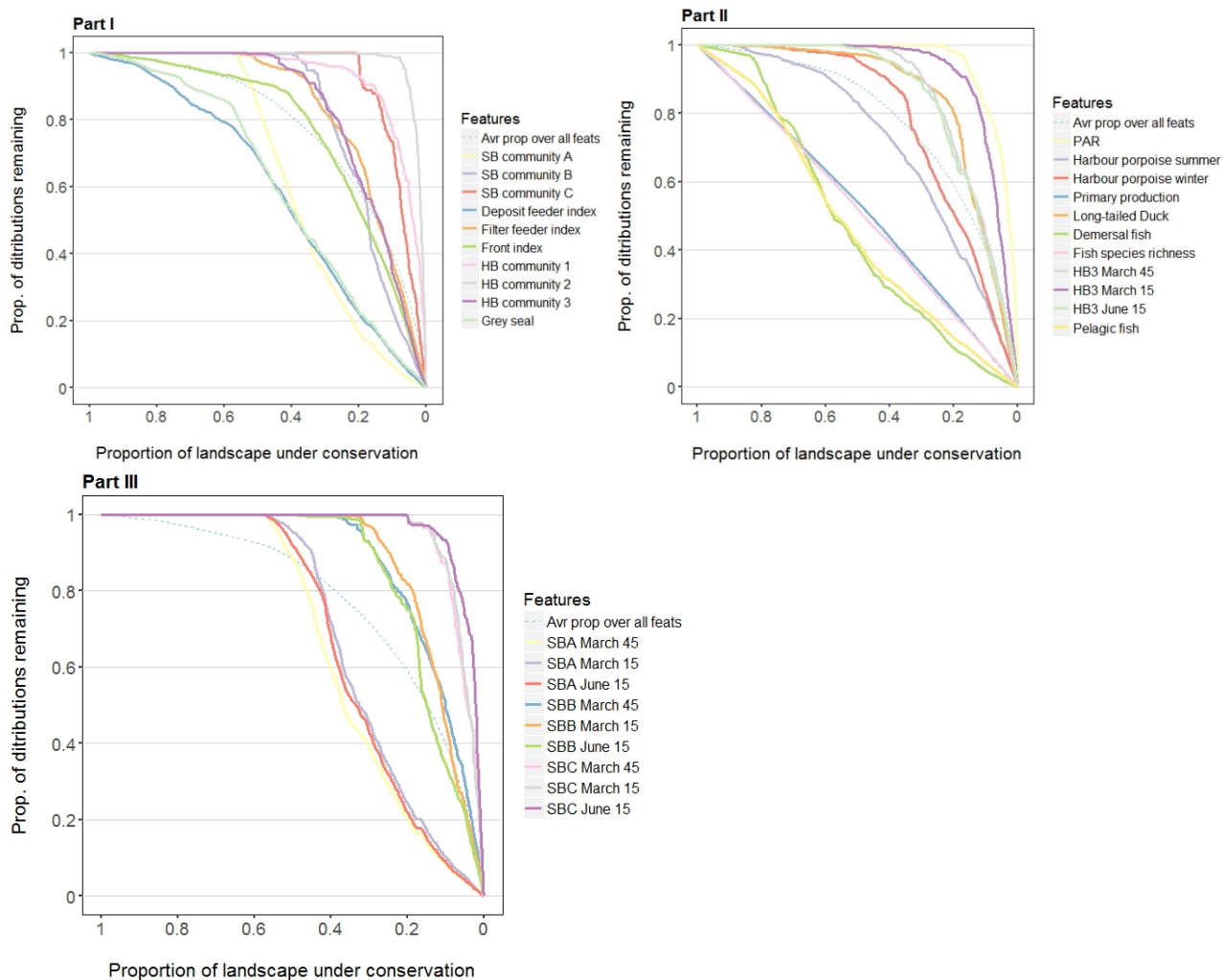


Figure 75 Zonation performance curves for theme 1a in the Baltic Sea shown in 3 graphs. The biodiversity features are weighted so that soft bottom and hard bottom communities as well as pelagic features get the same weight. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

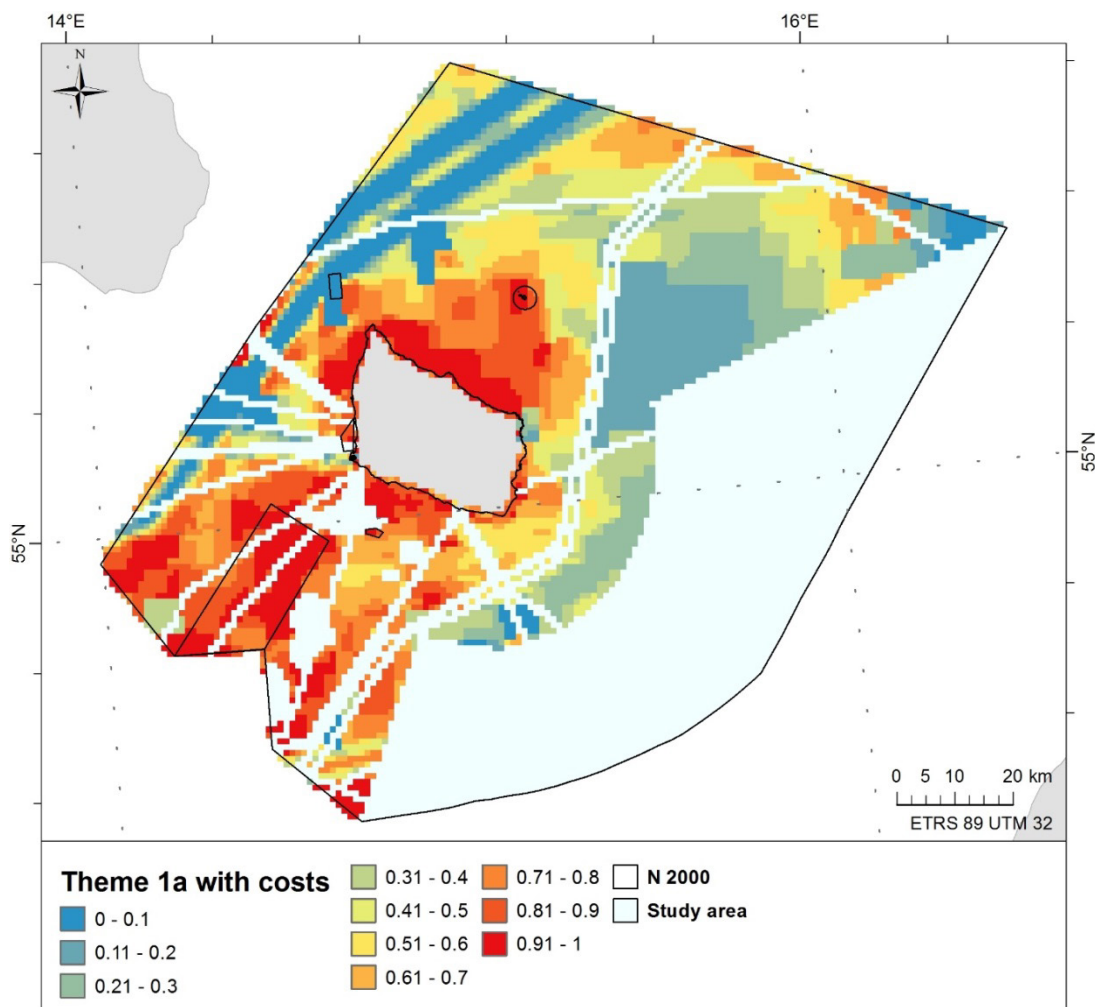


Figure 76 Zonation priority ranking map for theme 1A in the Baltic Sea, when costs and exclusions are considered. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

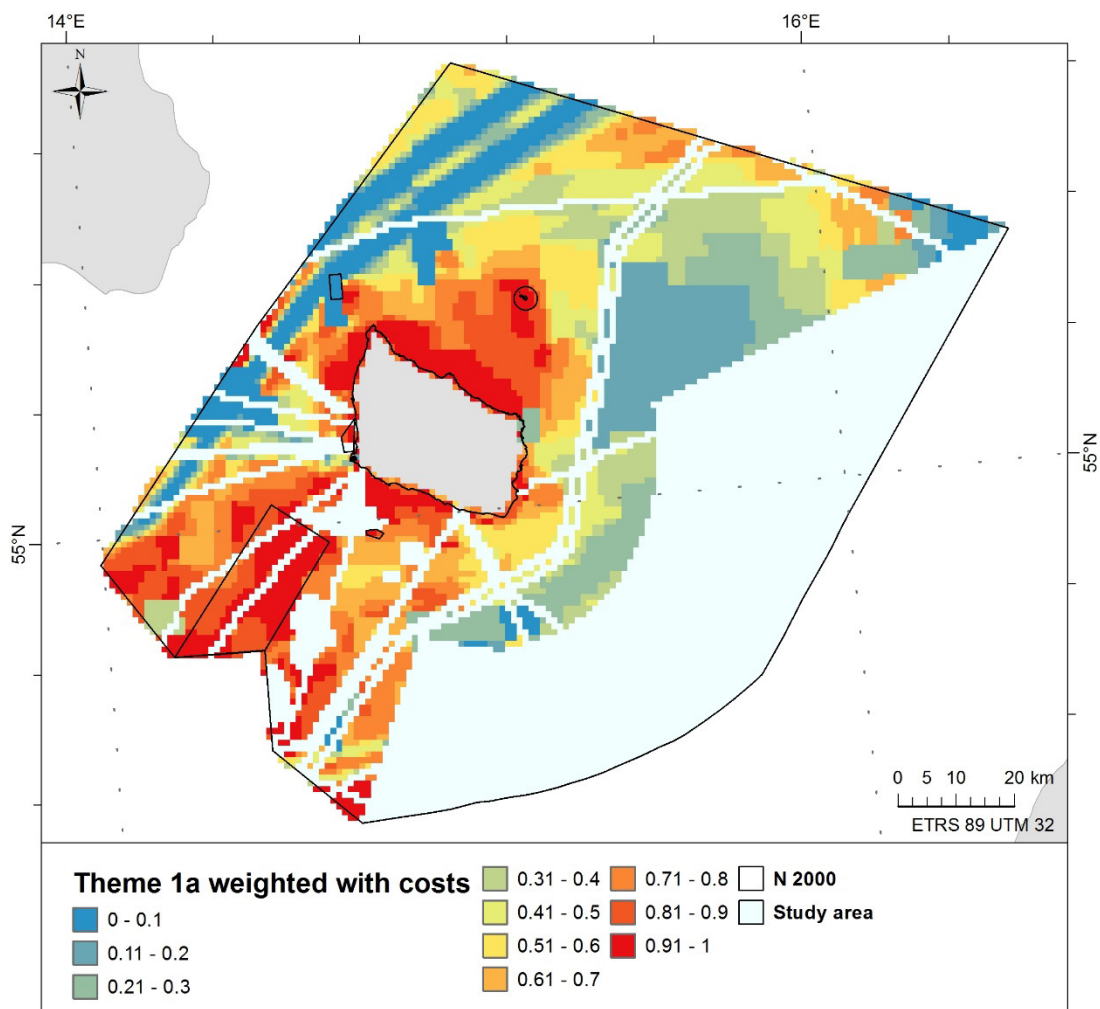


Figure 77 Zonation priority ranking map for theme 1A in the Baltic Sea, when costs and exclusions are considered. The biodiversity features are weighted so that soft bottom and hard bottom communities as well as pelagic features get the same weight. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

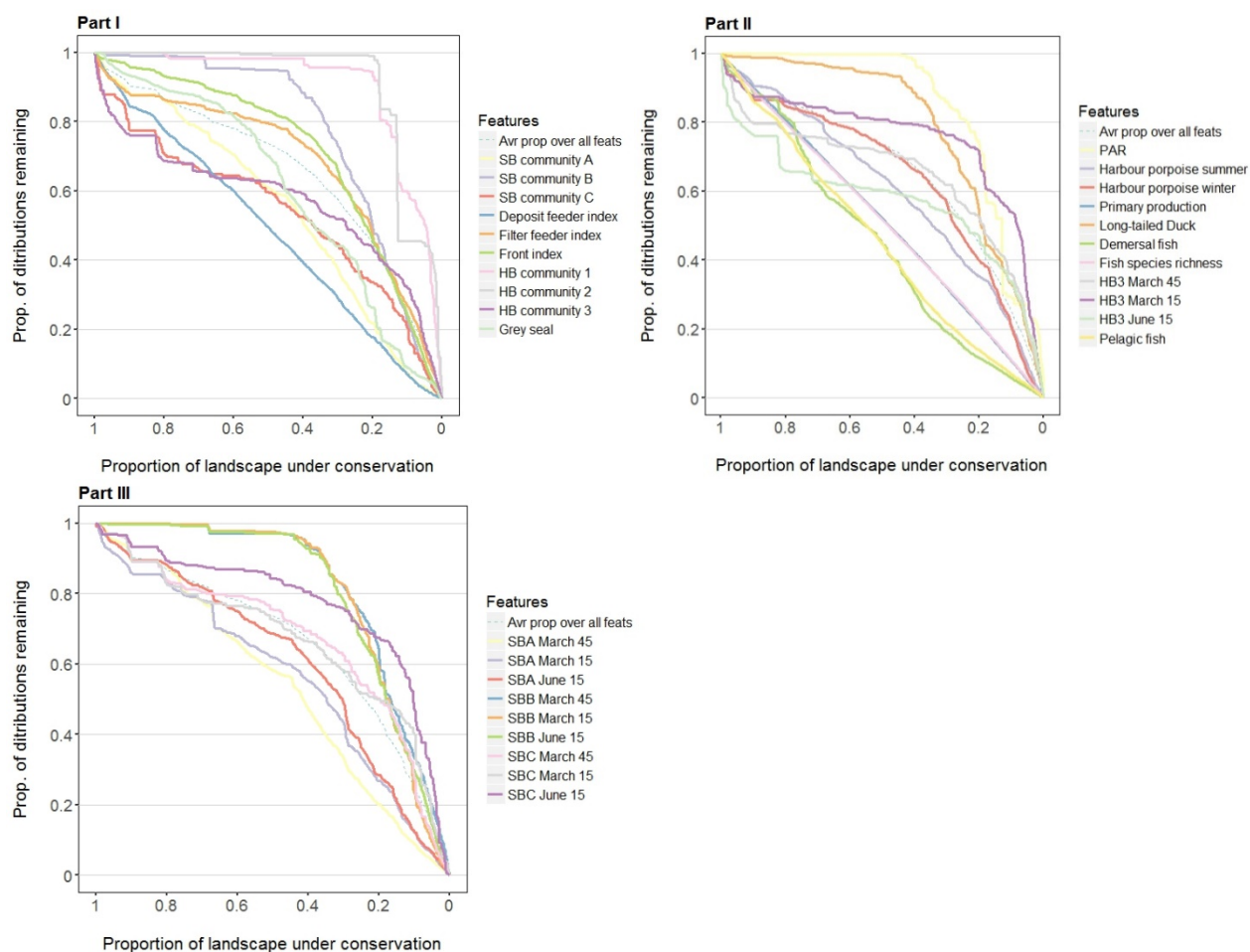


Figure 78 Zonation performance curves for theme 1a in the Baltic Sea, shown in 3 graphs, when costs and exclusions are considered. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

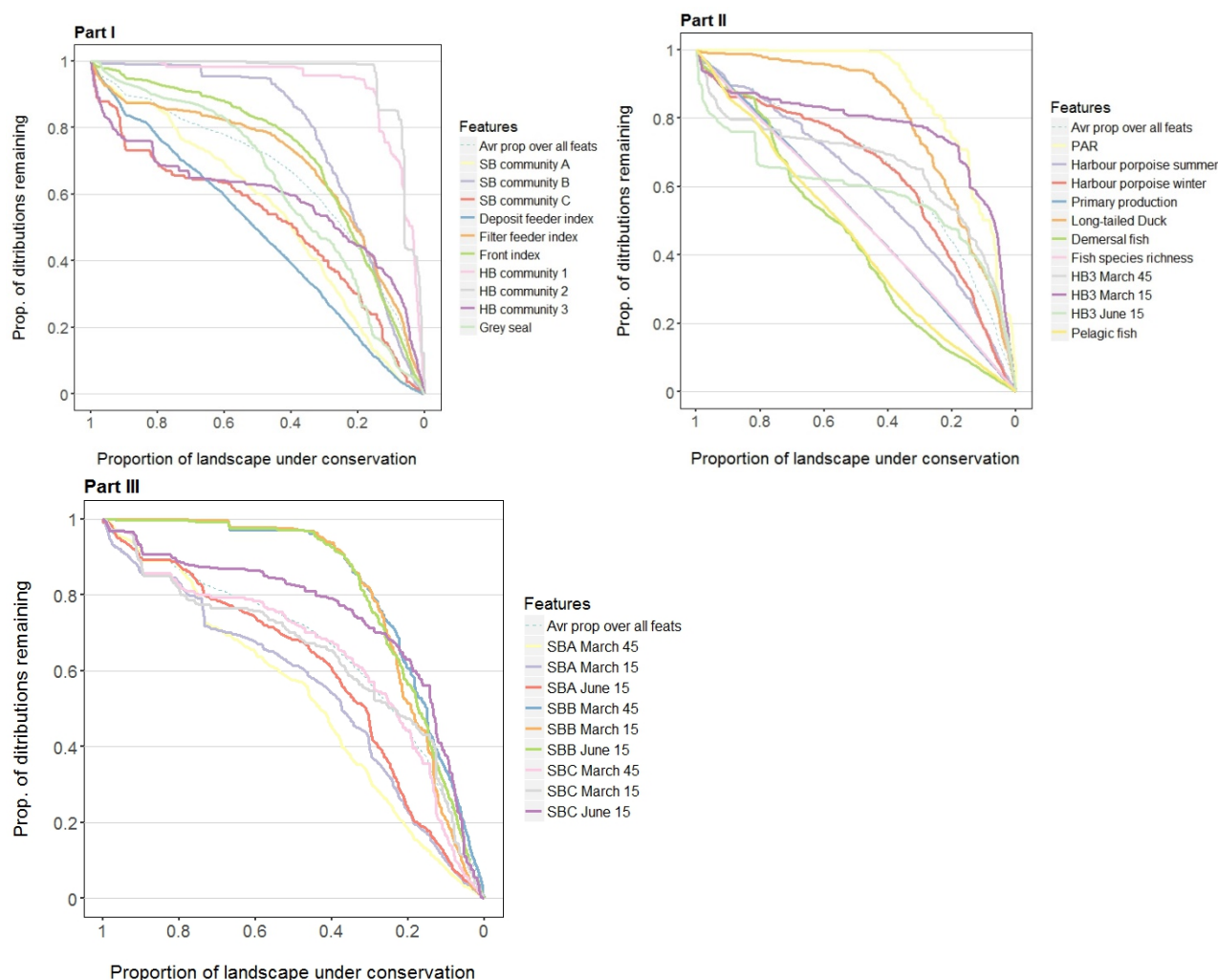


Figure 79 Zonation performance curves for theme 1a in the Baltic Sea shown in 3 graphs, when costs and exclusions are considered. The biodiversity features are weighted so that soft bottom and hard bottom communities as well as pelagic features get the same weight. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

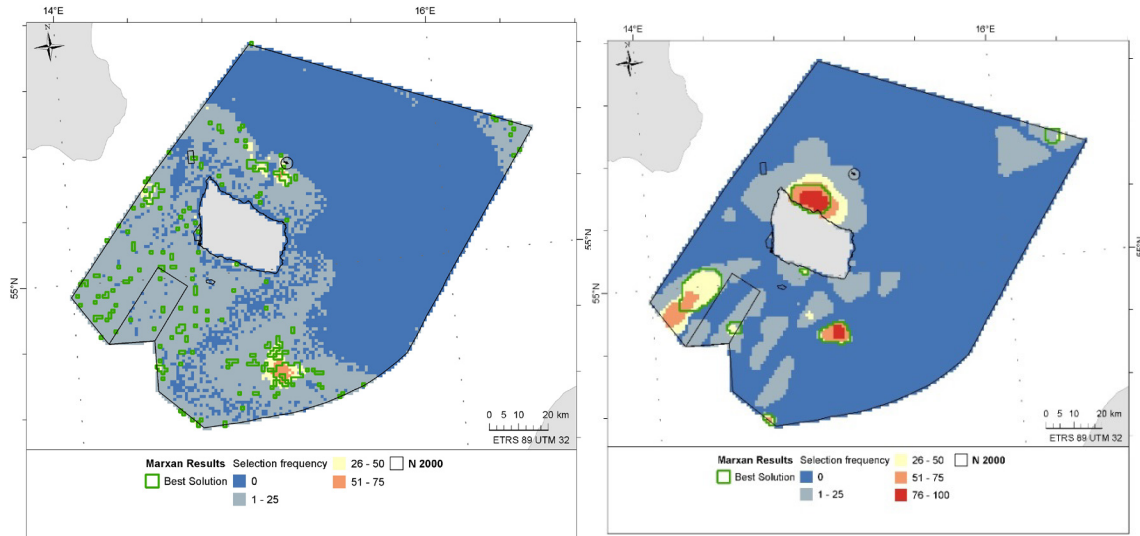
9.5.2.3 Marxan results

Similar to the approach for theme 1a in the North Sea, the targets and the penalty were reduced to half of the scenario target and the default penalty factor for primary production, the front index and fish data.

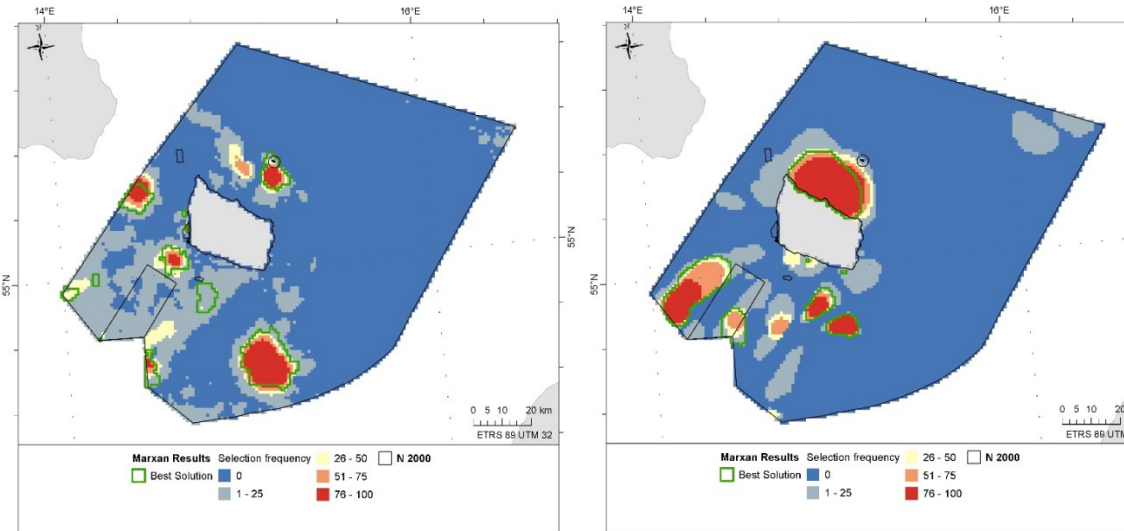
For this theme, the solutions with low target and without costs in Marxan are very scattered and have a low selection frequency. This indicates that there are many spatial solutions to reach the low target. The area that gets selected with a low frequency for the 5% target has similarity with the hotspots in Figure 72.

Similar to the Zonation analysis, without costs, the selection indicates that the area south and southwest of Bornholm is most important. When introducing costs the results shift to the area between Bornholm and Christiansø. For 20% target, it is necessary to increase the area from 1215 km² to 1931 km² (159%) to reach the targets with costs. Because using a normalization that sets the maximum value 1 for all input layers and the input layers differ in the two areas, it was not possible to balance the setup in the North Sea and for the Baltic Sea exactly the same way. However, it does not mean that the conflicts in the North Sea are necessarily more severe because the targets could not always be met for theme 1a there.

5%



10%



20%

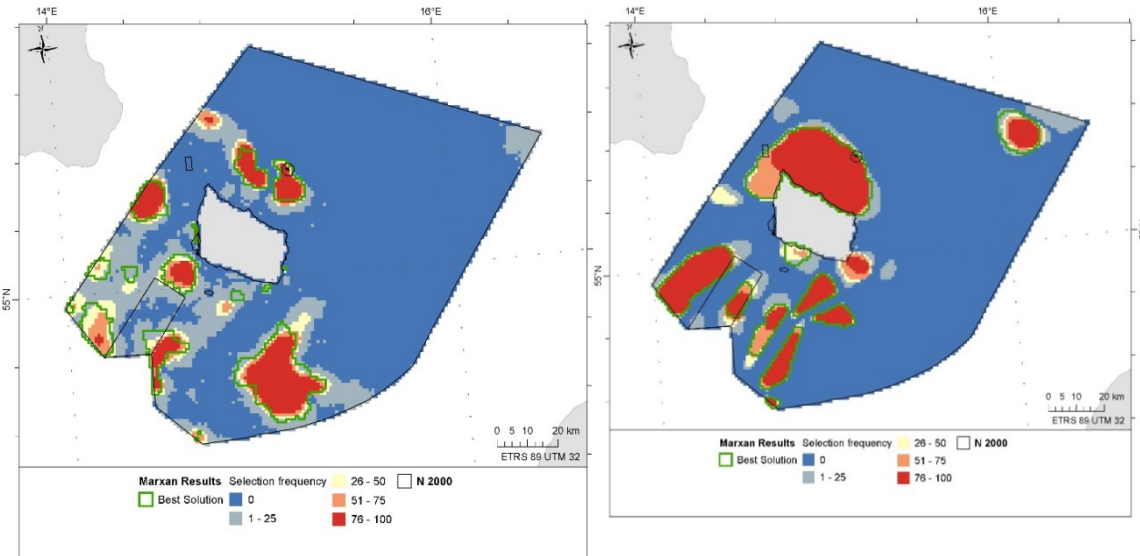


Figure 80 Suitable new sites with protection targets 5 % (top), 10% (middle), and 20% (bottom) for the features of theme 1a in the Baltic Sea, on the left without accounting for the costs and exclusions, on the right when cost and exclusions are accounted for.

9.5.3 Theme 1b

In theme 1b only hotspots without costs are modelled, because theme 1b mostly is used to describe, what a defined set of surrogate layers can achieve. Further, it also indicates, whether the patterns are robust or not; if similar patterns are obtained using a different set of ecological variables, it can be considered as a sign of robustness of the model solution.

9.5.3.1 Zonation results

The results of theme 1b, when only using surrogate layers, are similar to theme 1a where all features were included (Figure 81, Figure 82). The surrogate layers are therefore capable of describing quite well the valuable areas for a wider set of features. The similar patterns are also an indication of robustness.

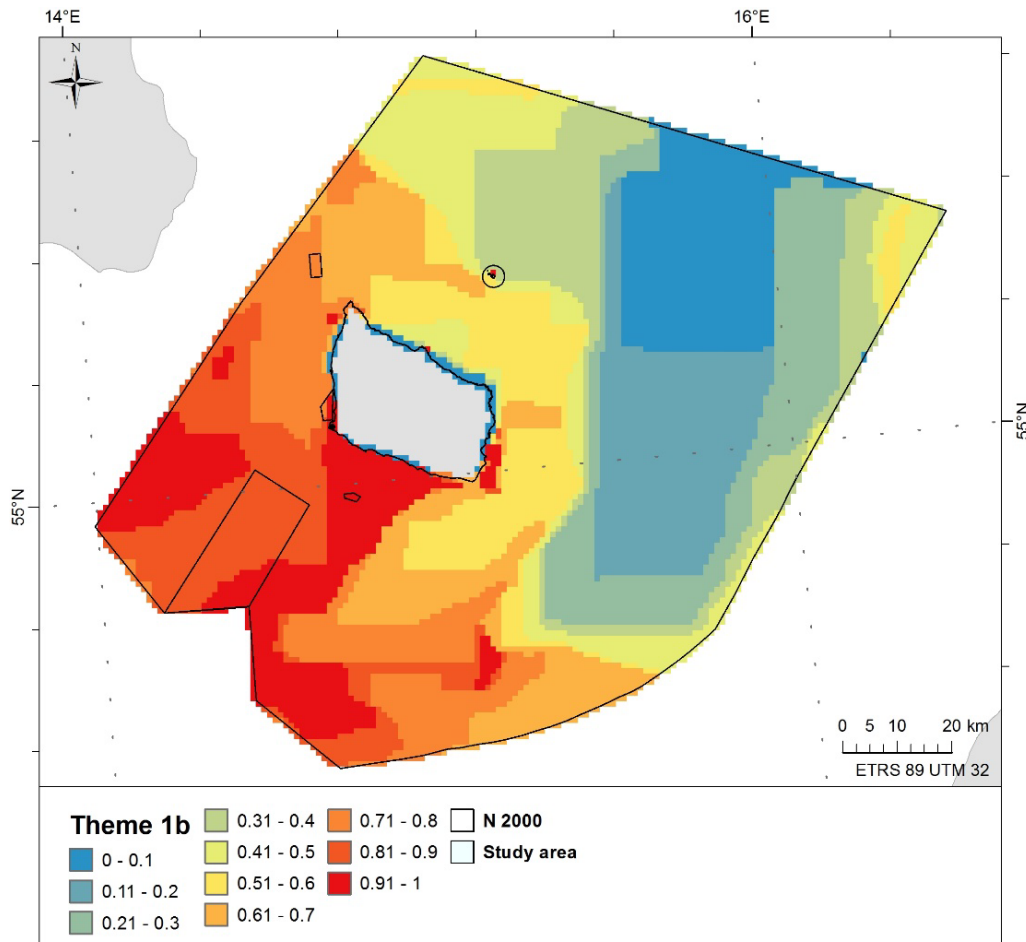


Figure 81 Zonation priority ranking map for theme 1B in the Baltic Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

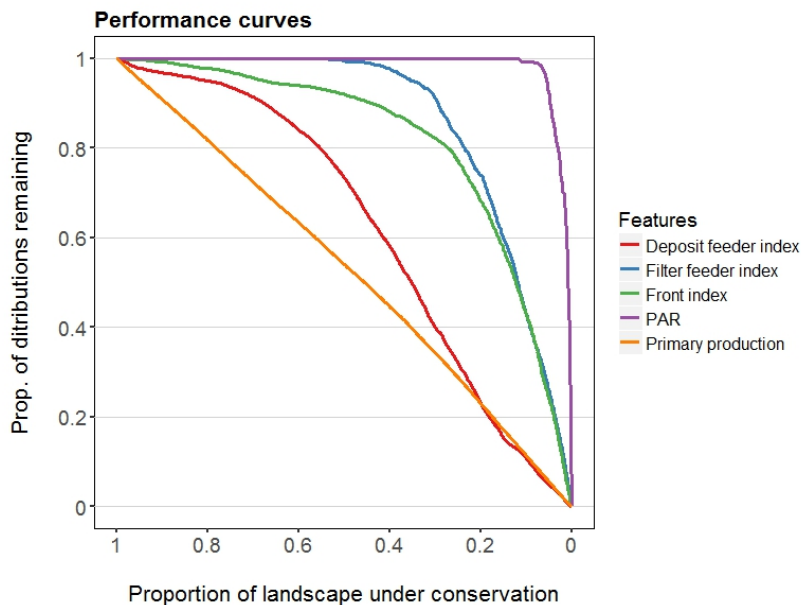


Figure 82 Zonation performance curves for theme 1B in the Baltic Sea. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

9.5.4 Theme 2 Soft bottom

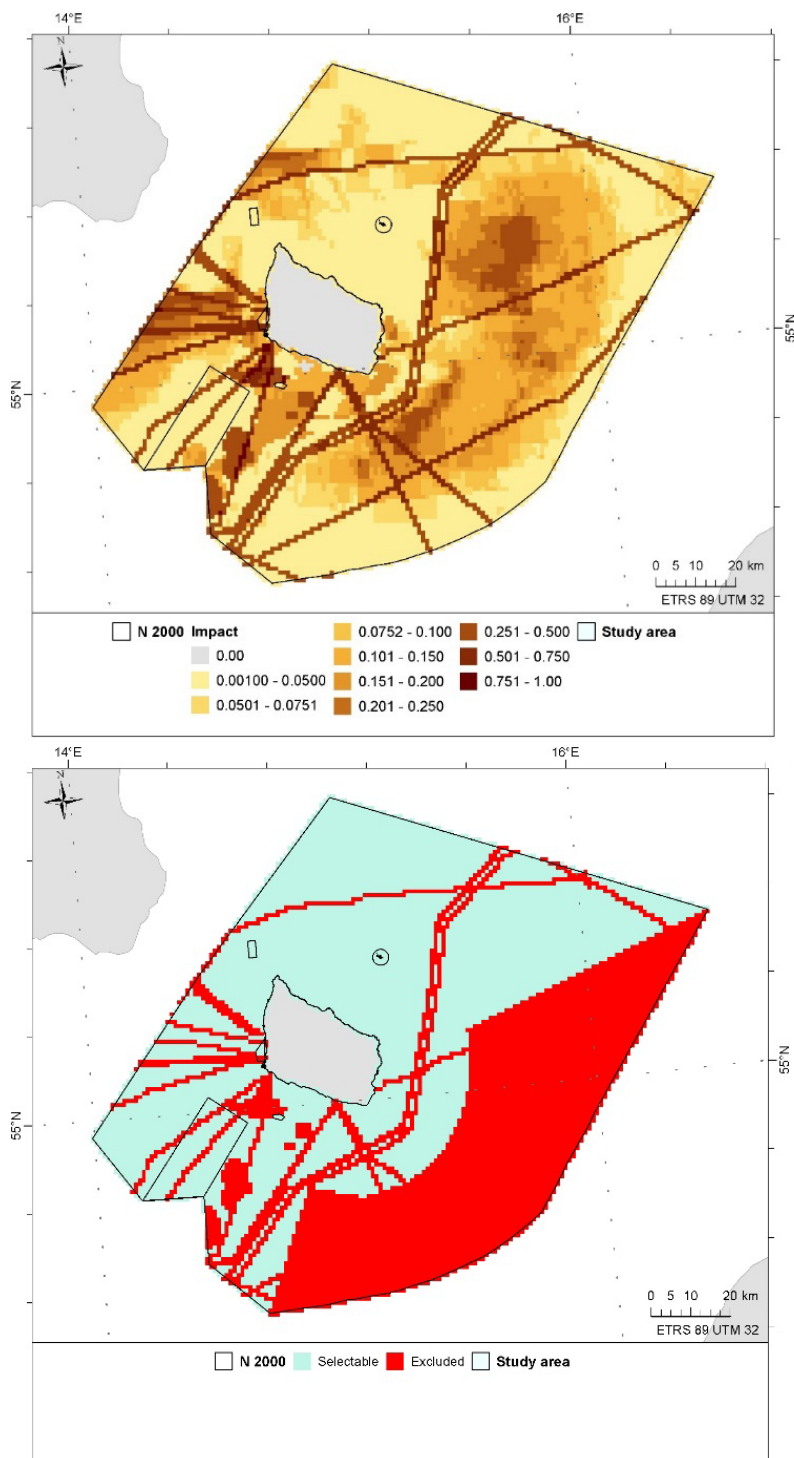
9.5.4.1 Impacts and economic interests

To identify the impacts and economic interests that are of importance for the benthic habitats, the relevant fishery first hand landing values (Danish seine, otter trawl) were summed up before normalization as well as the two area swept ratios. Cables and pipelines were combined into one presence – absence layer. The aggregates are combined into one layer, giving the highest value to the current production areas, a medium value to reserved common areas and the lowest value to potential areas. Military operations were not assumed to interfere with bottom trawling or cause reduced benthic quality. Military areas were therefore not included as a separate layer.

After normalization the layers were combined as follows:

Economic interests and Impacts = Dumped Munition*0.2+Pipeline&Cable+Offshore
Windpower+Aggregates+Swept Area Ratio*0.5+Fishery Value*0.5

The impacts and economic interests for theme 2 show similar patterns as in theme 1a with the major difference that the areas influence by ship traffic are not included. This leads to lower impacts especially in the northernmost corner of the area. The differences in taking only fisheries that is relevant for soft bottom compared to all fisheries are not so strong. The same features lead to exclusion as in theme 1a (Figure 83).



Impacts:

- First hand landing value for fisheries with active gear with bottom contact
- Fisheries swept area
- Aggregates licensed and potential for sediment extraction
- Planned offshore windpower
- Cables and pipelines
- Munition dumping sites (weight 0.2)

Not available for Protection

(same as for 1a):

- Pipeline & cables
- Offshore windpower planned
- Sediment extraction licensed
- Polish claim

Figure 83 Impacts, economic interests and areas not available for protection for the theme 2 in the Baltic Sea.

9.5.4.2 Zonation results

Like the North Sea results, the results of theme 2 for Baltic Sea indicate that only using features describing soft bottom habitats results in quite similar patterns as when including all features, the area southwest and south of Bornholm was ranked as the most valuable areas (Figure 84). The performance curves indicate that

the proportion of remaining feature distribution is quite high for most of the features already at a relatively low level of protection (Figure 86). Inclusion of economic interests and pressures, changes the patterns slightly but the performance are still good according to the performance curves (Figure 85Figure 87).

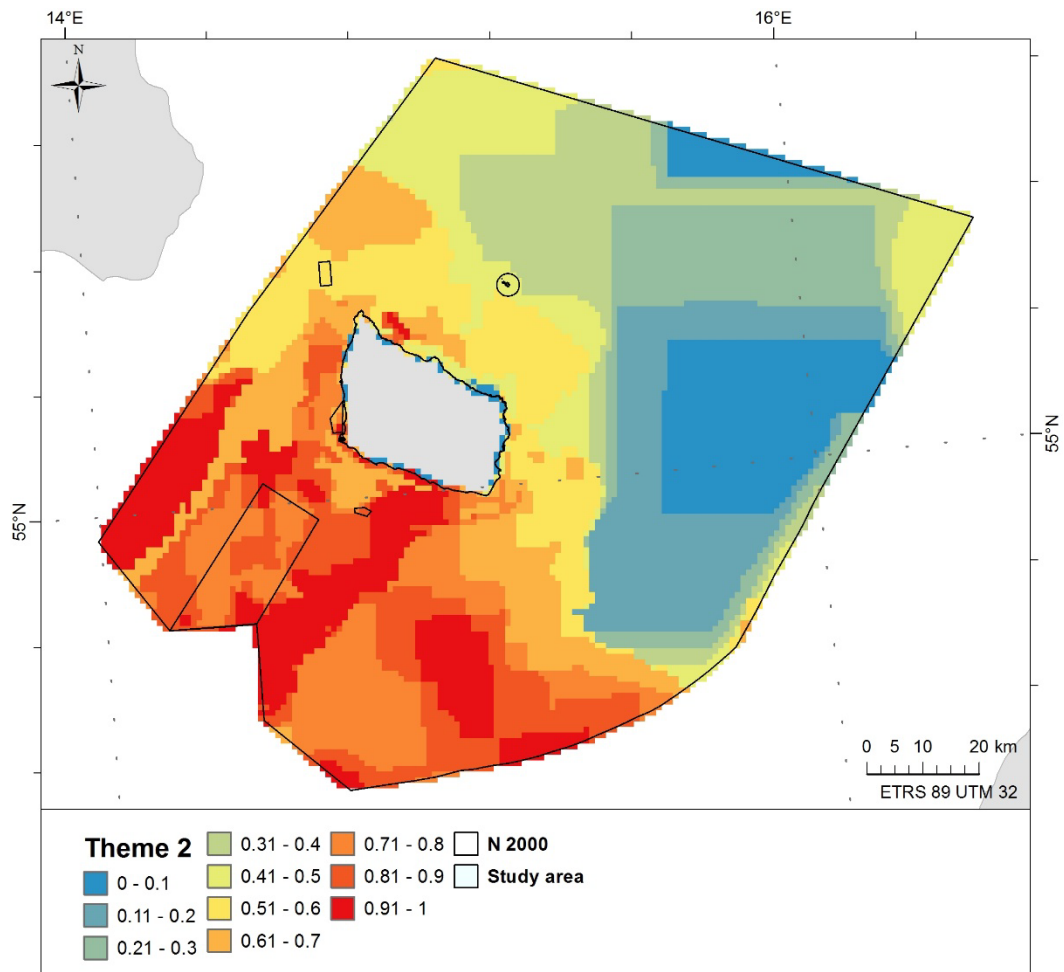


Figure 84 Zonation priority ranking map for theme 2 in the Baltic Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

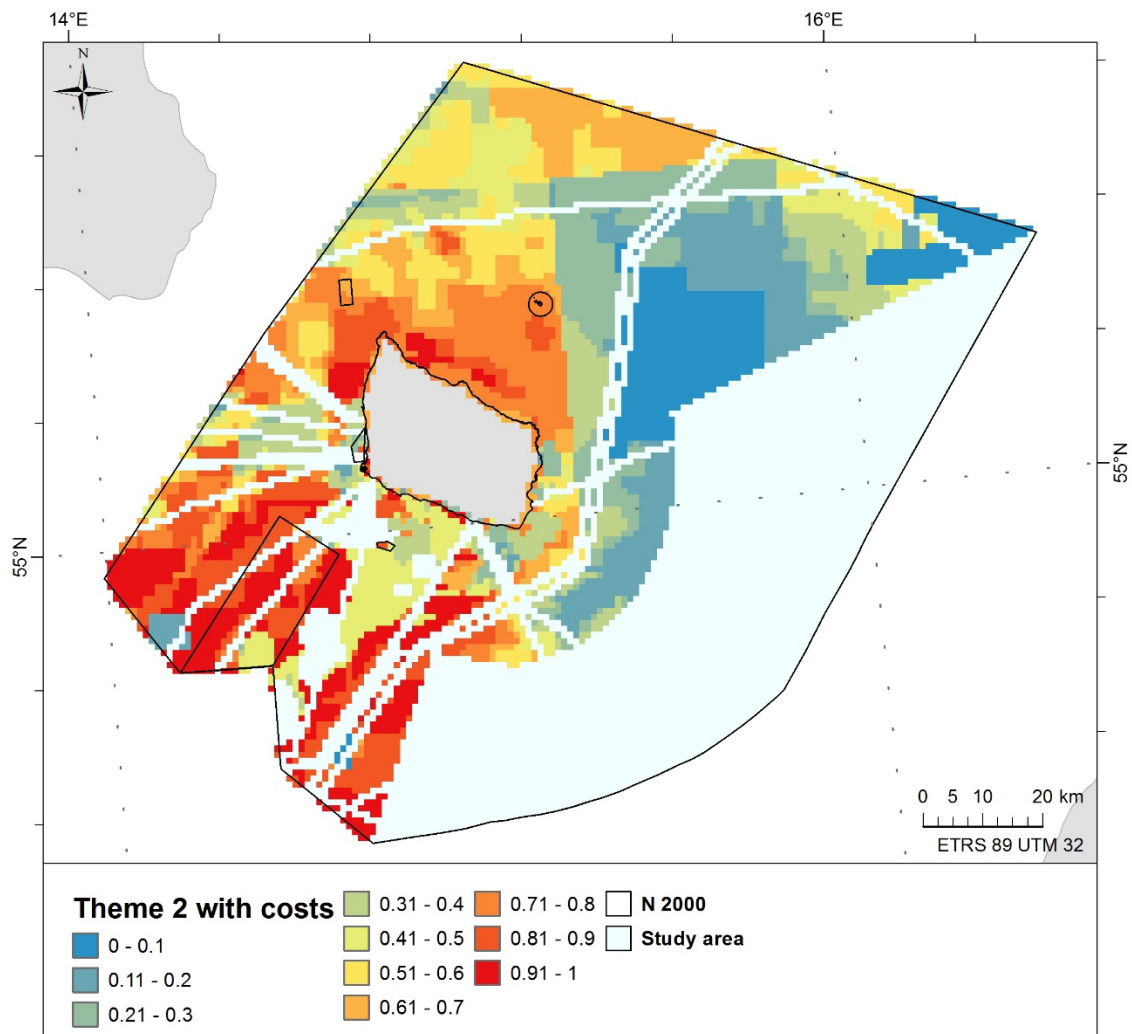


Figure 85 Zonation priority ranking map for theme 2 in the Baltic Sea, with costs and exclusions considered. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

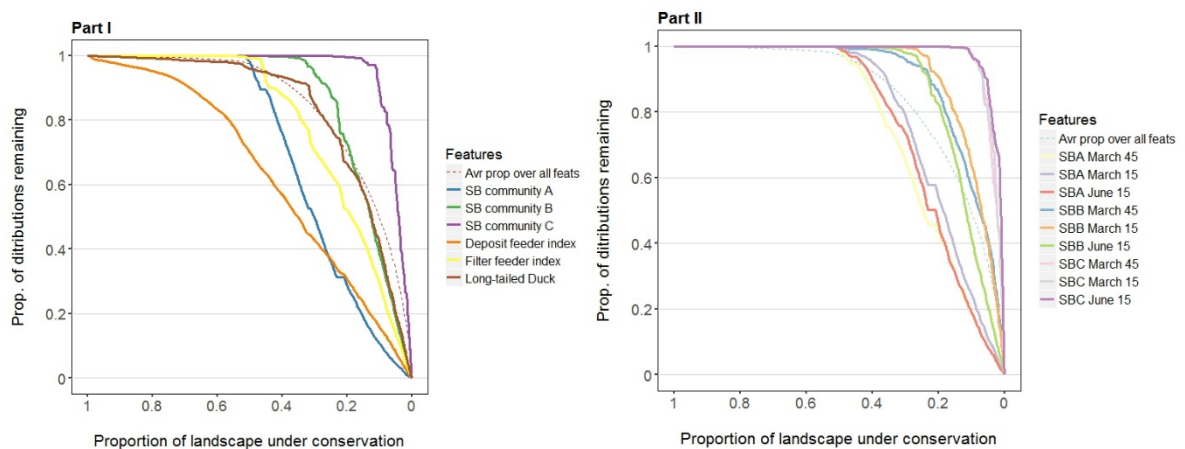


Figure 86 Zonation performance curves for theme 2 in the Baltic Sea, shown in 2 graphs. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

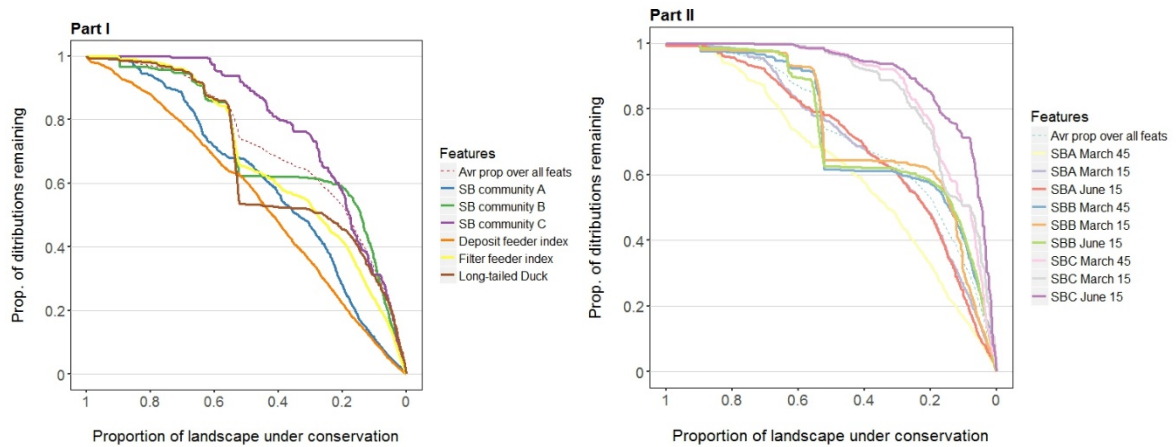
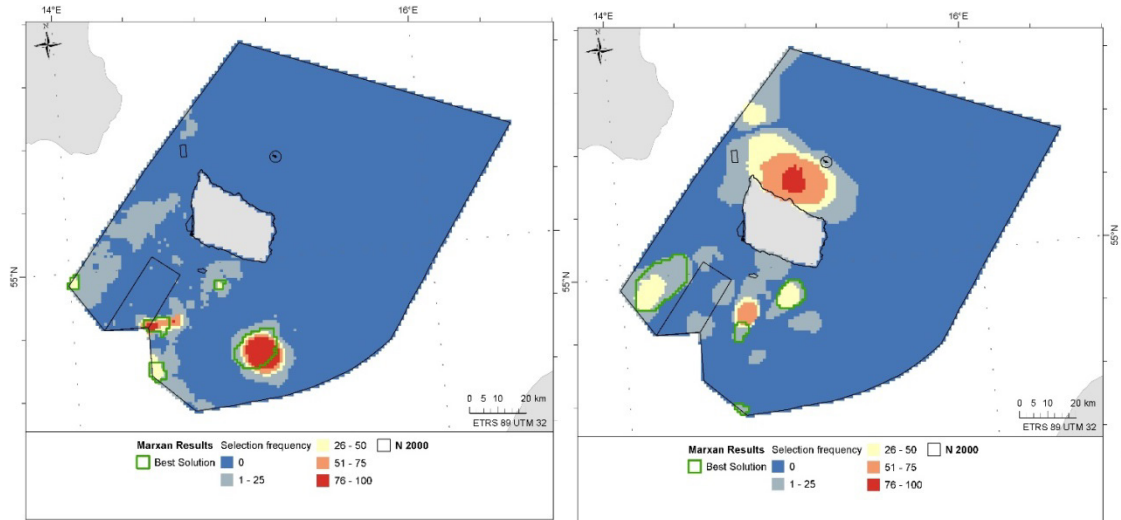


Figure 87 Zonation performance curves for theme 1a in the Baltic Sea, shown in 3 graphs, when costs and exclusions are considered. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

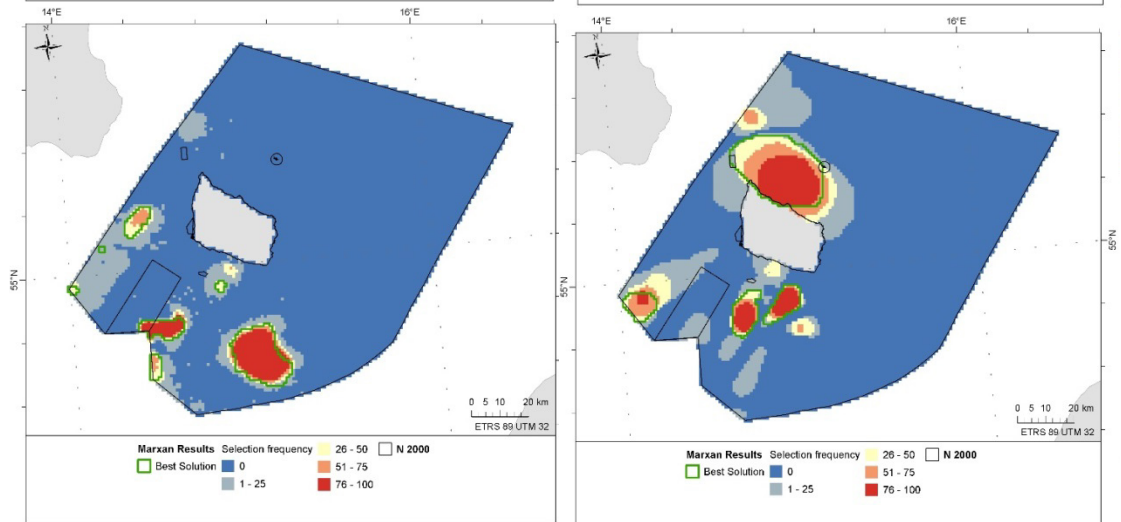
9.5.4.3 Marxan results

For the soft bottom, the southwestern part provides the best conditions and the connectivity for this area is best. The biggest connected area lies in the economic zone at the border to Poland which is excluded in the series on the right panel of Figure 87. When the targets are increased it is not possible to select the most optimal areas in the south, an area north of Bornholm becomes increasingly selected (Figure 88). This leads to an increase in the selected area. For the target 20%, the area selected is 1074 km² while it is 158% of that size (1698 km²) when avoiding conflicts as well as possible.

5%



10%



20%

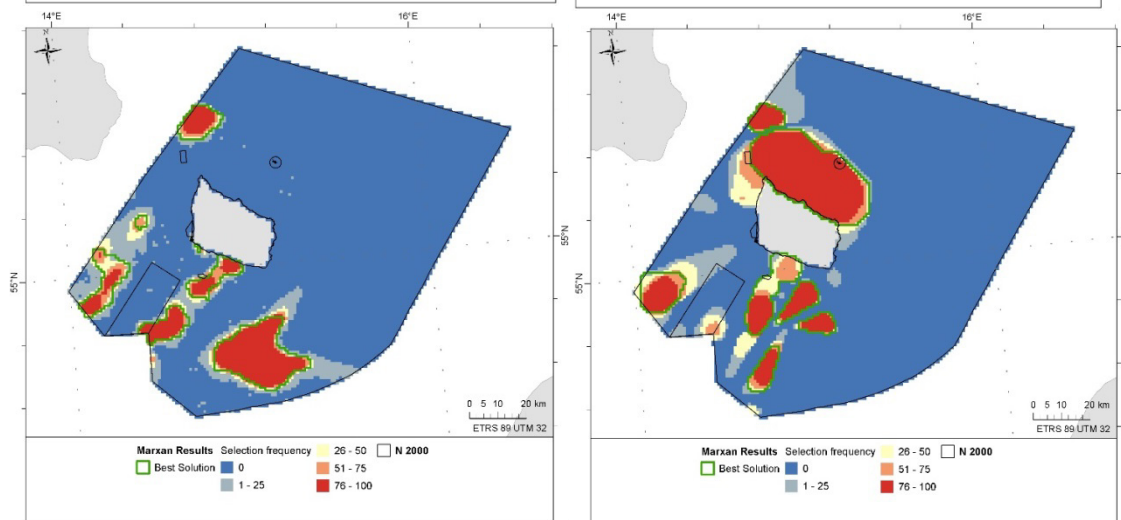


Figure 88 Suitable new sites with protection targets 5 % (top), 10% (middle) and 20% (bottom) for the features of theme 2 in the Baltic Sea, on the left without accounting for the costs and exclusions, on the right when cost and exclusions are accounted for.

9.5.5 Theme 3 MSFD

9.5.5.1 Impacts and economic interests

The impacts and economic interests are the same as for theme 1a, chapter 1.5.2.1.

9.5.5.2 Zonation results

The results from theme 3 are quite similar, which is not surprising as this theme is “in between” theme 1 and 2 (Figure 89, Figure 91). The consideration of competing interests also achieves a good performance although the spatial patterns are changed (Figure 90, Figure 92).

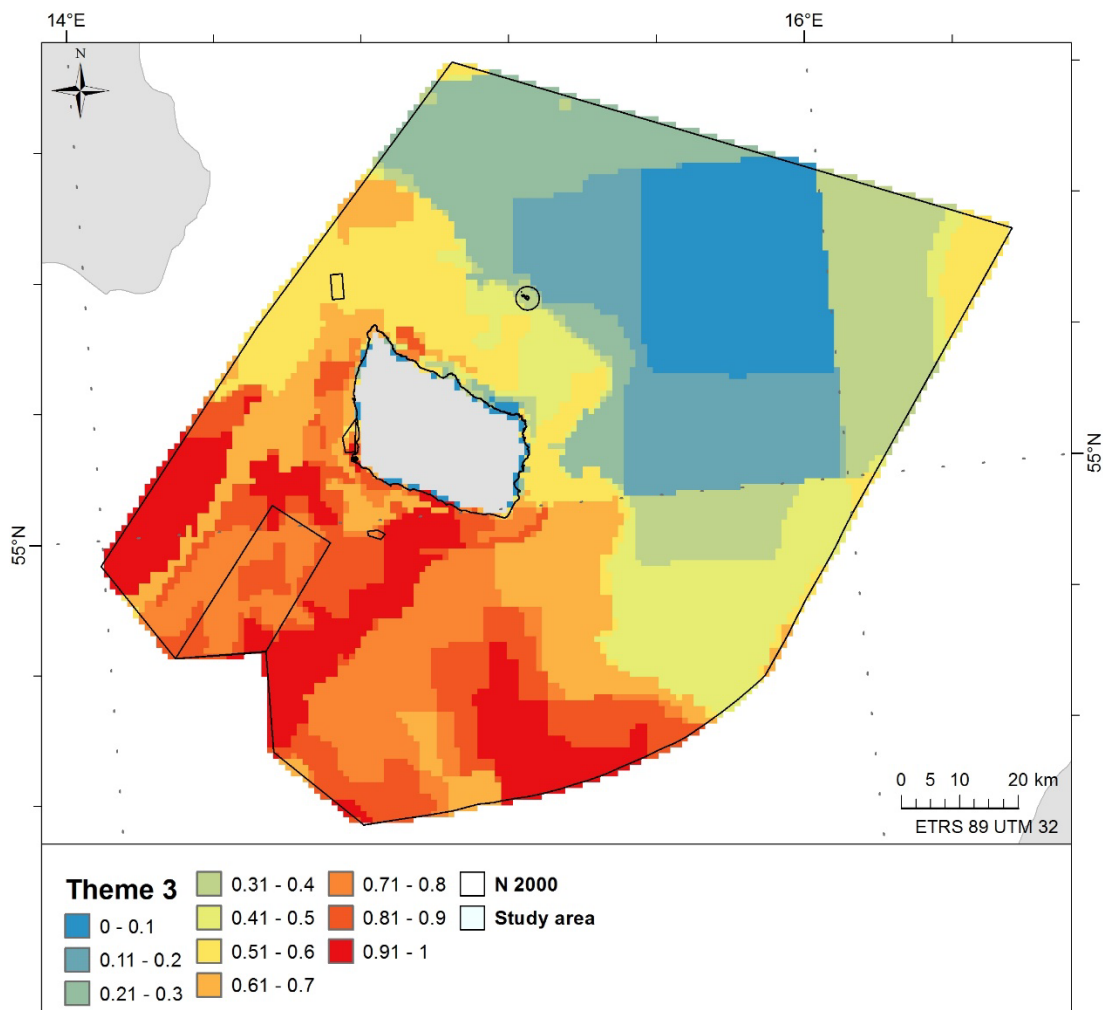


Figure 89 Zonation priority ranking map for theme 3 in the Baltic Sea. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

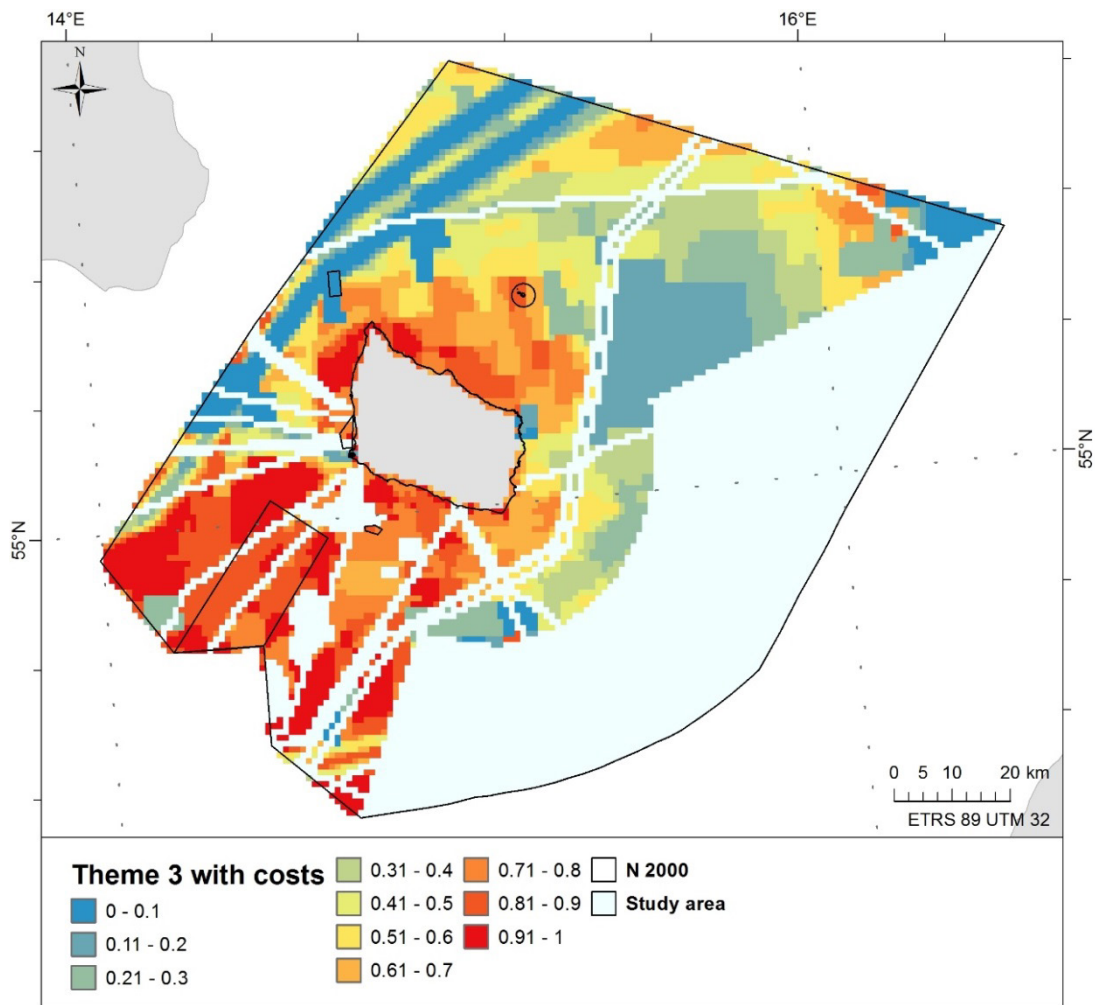


Figure 90 Priority ranking map for theme 3 in the Baltic Sea, when costs and exclusions are considered. The ranking is classified into 10% classes, i.e. dark red = most valuable 10%, dark blue least valuable 10%.

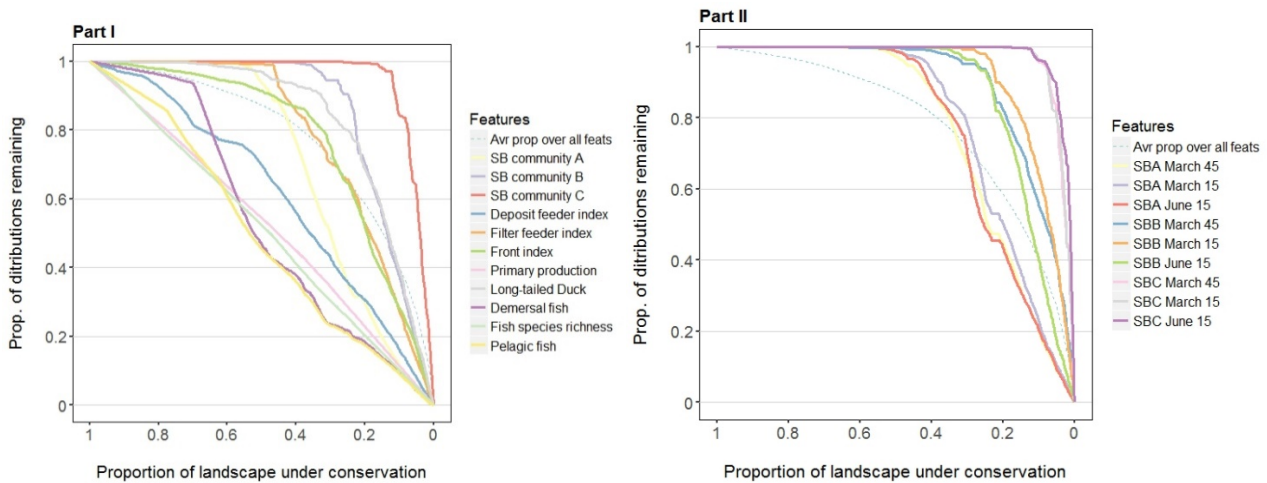


Figure 91 Zonation performance curves for theme 3 in the Baltic Sea, shown in 2 graphs. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

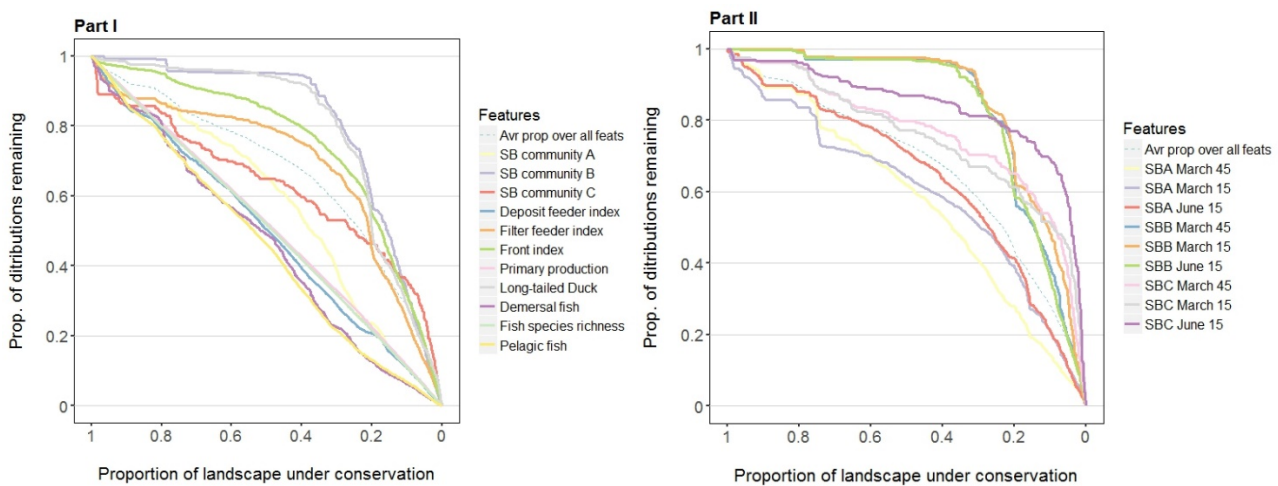
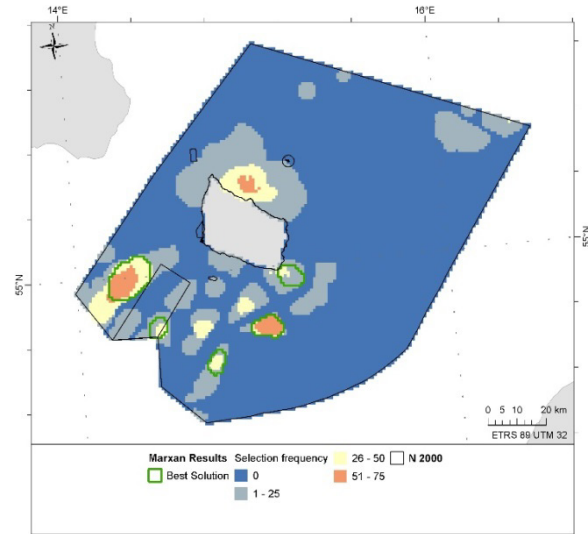
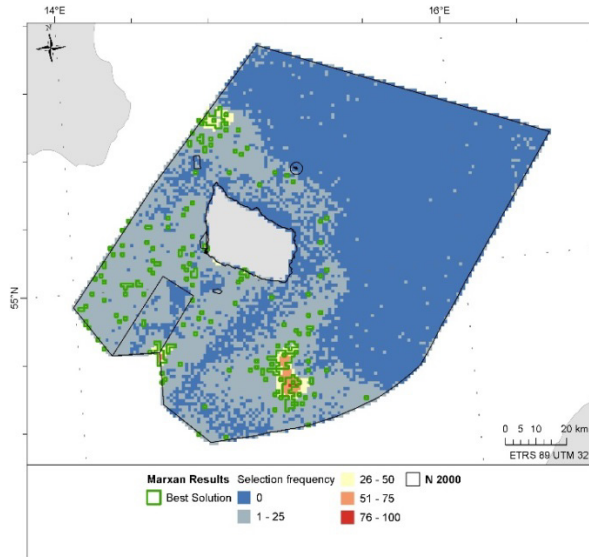


Figure 92 Zonation performance curves for theme 3 in the Baltic Sea, shown in 2 graphs, when costs and exclusions are considered. Each line depicts one feature and describes the proportion of the feature specific distribution (y-axis) over varying proportion of protected area (x-axis).

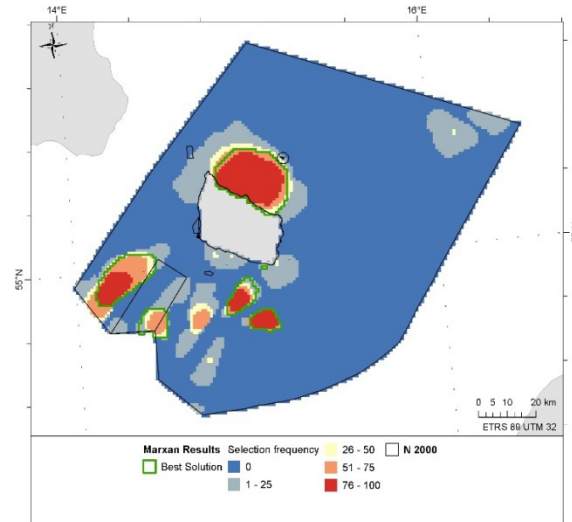
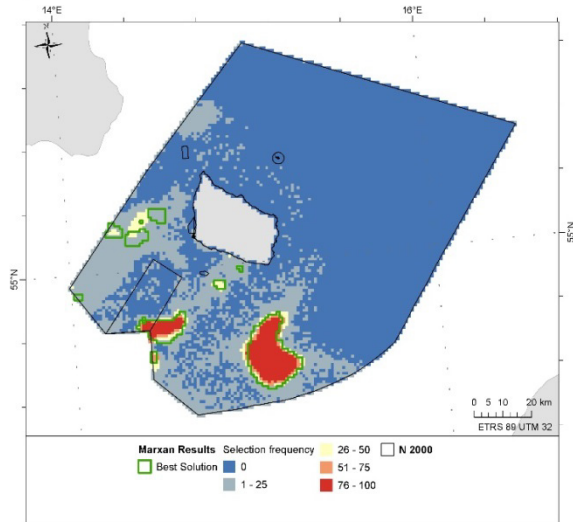
9.5.5.3 Marxan results

Similar to theme 1a, there are many options for new sites with low targets and without conflicts. As in the two other themes, when conflicts are introduced, the area between Bornholm and Christiansø gets increasingly selected. This leads to an increase in the selected area. For the target 20%, the area selected is 1110 km² while it is 169% of that size (1879 km²) when avoiding conflicts as well as possible.

5%



10%



20%

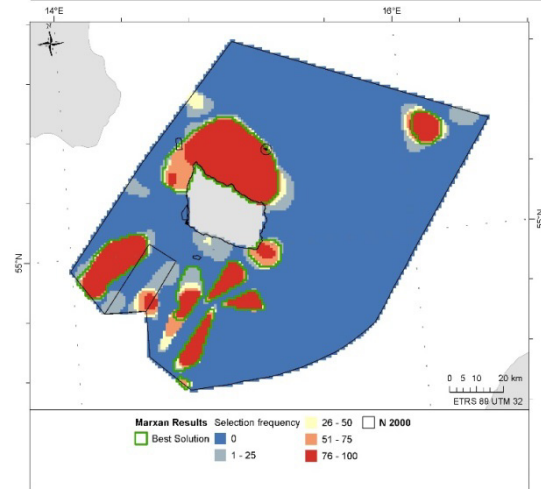
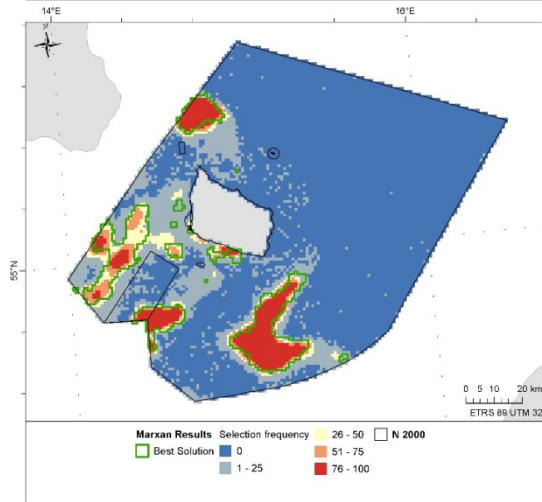


Figure 93 Suitable new sites with protection targets 5 % (top), 10% (middle) and 20% (bottom) for the features of theme 3 in the Baltic Sea, on the left without accounting for the costs and exclusions, on the right when cost and exclusions are accounted for

9.6 Displacement of fishing activities

9.6.1 The DISPLACE model

DISPLACE is an agent-based model that describes the fishing activities of individual vessels. It covers several fisheries and stocks and mimics the decisions fishermen take based on their knowledge about potential fishing areas, changes in fisheries management regulations, economic factors, fish abundance, and spatial and seasonal patterns in resource availability (derived from scientific surveys). Each vessel fishes for a set of species and retains part of the catches on board for landings depending on the individual quotas allotted to the vessel. Here we use DISPLACE to predict how closing an area to fishing is likely to re-allocate fishing activity, affect the fishermen and their economy, and change the biomass and functional characteristics of the benthos inside and outside the closed area. Further details about the model are provided in Annex 12-2.

9.6.2 Modelling the Danish fleet

DISPLACE was used to model the Danish fishing vessels that were active in the Baltic Sea and the North Sea in 2015. The simulations used hourly time steps and a 6 by 6 km geodesic spatial grid (providing 35,309 possible fishing locations). In all, 693 vessels were simulated representing 46% of the 1,505 Danish vessels for which logbooks were available in 2015. For 380 of the simulated vessels no VMS data were available. The remaining 812 vessels were all below 8m and were not simulated. Each simulated vessel could only fish in the set of EUNIS habitats and areas where it had previously been fishing. The simulated fishing vessels were allowed to use several different gear types within the same trip. After each trip, the simulated vessels return to port and earn money from selling their landings in the harbor. Fish prices are given per stock and marketable category (small, medium, large) and the gross added value is computed from income generated by selling the landings and the actual operating costs of the trip.

The model included 39 fish populations in total. Analytical assessments exist for 11 of these species. For these 11 species the population dynamics were explicitly modelled. The population model used is size-based, and split each stock into 14 body size groups arranged in 5 cm classes. Fishing fleet dynamics are modelled by aggregating the results from individual fishing vessels, where each vessel is allowed to participate in one (or several) type of fishing activities defined by specific fishing métiers¹ (17 fishing métiers at EU DCF (EU Data Collection Framework) level 6) with a unique gear selectivity for each stock.

Fish below the Minimum Landings size specific to each stock are discarded. When a discard ban is active (as it was in this application), discards are counted in the TACs², but does not generate income. All harbors visited by the Danish fleet are accounted for (302 ports including foreign ports) and are the locations for landing the catches (landings only i.e. the marketable fish). Fish prices are given per stock and commercial category (small, medium, large). At the time of writing, the variables describing the economics of the fisheries (e.g. fixed costs, opportunity costs, etc.) were derived from default parameter values. The management system simulated is an annual TAC system that follows the EU Common Fisheries Policy according to which all stocks should be fished at F_{MSY} ³ levels. Each annual TAC is split into individual vessel quotas using the same distribution key across years.

¹ A métier is defined as a fishing activity which is characterised by one catching gear and a group of target species, operating in a given area during a given season, within which each boat's effort exerts a similar exploitation pattern on a particular species or group of species. The species composition and size distribution in catches taken by any vessel working in a particular métier will thus be approximately the same. A métier is indicative of where and how boats work, not of the port of origin or landing.

² TAC: Total Allowable Catch, the total quota of a particular species allotted to Denmark.

³ F_{MSY} : Fishing mortality generating the Maximum Sustainable Yield (MSY)

Maps of benthos abundances per functional group were provided for the Baltic zone only. The information was derived from Gogina et al. (2016), who mapped the biomass density of the benthic fauna from samples collected across the Baltic Sea and linked the densities to the EU EMODNet EUNIS habitat classification scheme. 4 functional groups are simulated i.e. Polychaeta, Malacostraca, Bivalvia, and Echinoidea. We retrieved the depletion effect per type of trawl path and logistic recovery rates per functional groups and habitat type from the literature (e.g. Hiddink et al. 2017). However, this set of parameters may not be representative for the Baltic area and should therefore be revised when Baltic studies becomes available.

The “Danish Fleet” application with the input dataset used here is available online on request. Danish fishing vessels can fish both in the North Sea and in the Baltic Sea, and both areas must therefore be covered and simulated simultaneously in the model, making the spatial extent of the model very large (-4W to 18E, 51N to 62N). Due to runtime constraints we had to limit the number of replicate predictions for each scenario to 20.

9.6.3 Scenario testing

The consequences of a subset of the spatial management scenarios evaluated by Marxan in Theme 2 (protection of benthos from bottom trawling) were examined. We decided to predict the consequences of combinations of the spatial closures Marxan identified in the two zones in the 5% and 20% target runs while accounting for exclusions and economics. We also predicted the consequences of the closures resulting from adopting a 20% target in both zones without accounting for exclusions and economics. And we compared these five runs with a baseline run, where no closures were introduced. The Marxan results are described in sections 9.4.3 and 9.5.4 and the setup for modelling the fisheries consequences is presented in Table 3 in Annex 12-2.

The scenarios with combinations of 5% and 20% closures in the North Sea and the Baltic were selected for the DCF⁴-fleets indicated in Table 4. Note that these fleets include the impacted set gillnets (DCF-code: GNS_DEF), drifting long lines (LLD_ANA), otter trawl (OTB_CRU, OTB_DEF, OTB_MCD), shrimp beam trawl (TBB_CRU), Danish and Scottish seines (SDN_DEF & SSC_DEF), and the ‘other’ gears category (other). Parts of the Baltic Sea are presently closed for most commercial fishing from May to October and this closure (Area 1 in Table 3 in Annex 12-2) was implemented in all runs with the model.

To interpret the tables and plots displaying the results it is important to notice that:

- Svana_baseline is a status quo simulation with no closures.
- Svana_sub1mx20 is a simulation with closures corresponding to the Marxan 20% target in both zones without accounting for exclusions and economics.
- Svana_sub4mx20 is a simulation with closures corresponding to the Marxan 20% target in both zones while accounting for exclusions and economics.
- Svana_sub4mx5ns20bt is a simulation with closures corresponding to the Marxan 5% target in the North Sea zone and a 20% target in the Baltic zone while accounting for exclusions and economics.
- Svana_sub4mx20ns5bt is a simulation with closures corresponding to the Marxan 20% target in the North Sea zone and a 5% target in the Baltic zone while accounting for exclusions and economics.
- Svana_sub4mx5ns5bt is a simulation with closures corresponding to the Marxan 5% target in the North Sea zone and a 5% target in the Baltic zone while accounting for exclusions and economics.

⁴ DCF: EU Data Collection Framework in which the fishing gear categories used are specified

9.6.4 Main simulation outcomes

The changes in the spatial distribution of catches (Figure 94) unwanted catches (Figure 95), effort allocation (Figure 96) and swept area (Figure 97) show the potential effect of the re-allocation of fishing vessels after the closures have been implemented. Compared to the baseline, the model predicts a reduction of the overall effective effort deployed at sea, but a local increase of fishing effort in some areas. Fish stocks and benthos generally benefit from less overall fishing pressure, but some areas become more affected due to the re-allocation. Part of the Danish fleet compensated for the lost catch opportunities in the closed areas by moving to remote areas, another part started fishing close to the borders of the closed areas.

Overall, in the 20% target closure situation with exclusions and economics both fisheries income (net present value, NPV), catch (catch per unit effort, CPUE) and fuel efficiency (value per unit fuel, VPUF) were reduced by 10% (box plot) mainly due to losses on the Baltic Sea side (>25%, box plot). In the North Sea the Danish fleet suffered a moderate loss only (about -5% (Figure 98) box plot). The negative effect is a result of the activity of only a few vessels, those likely being hit hard by lacking alternative fishing opportunities. Hence, looking at the vessels individually shows that most of the vessels (> 85%, Figure 99 stress bar plot) are not negatively affected by the tested closures; on the contrary, most succeed in gaining additional revenues. No strong distributional effect on revenues is further revealed, all fishing harbors being affected more or less equally, apart again from Bornholm harbors that are strongly impacted by the Baltic area restrictions (Figure 101, pie chart per harbor). The accumulated gross value added of the entire Danish fleet (Figure 103) is reduced compared to the baseline in both 20+20% scenarios, and this reduction is largest on the Baltic Sea side.

Especially, the model simulations anticipate that:

- Theme 2 (20%+20% with exclusions and economics) might lead to additional pressure on the North Sea cod and sole stocks, while at the same time reducing catches from the Eastern Baltic cod stock and lowering the associated risk of unwanted catches (formerly called “discards”). No other impact is detected on other stocks fished by the Danish fleet.
- Theme 2 makes the Danish fishing vessels less economically efficient and fishing more costly. Both on the North Sea and Baltic Sea side fishermen spent more time steaming to reach a suitable fishing ground, therefore lowering their fuel efficiency, eventually adversely impacting the revenue per unit of area swept and the gross value added.
- Theme 2 (20%+20% without exclusions and economics) will only slightly affect the Danish fisheries by preventing catch opportunities on the North Sea plaice stocks. No other impact is detected on other stocks fished by the Danish fleet (The North Sea plaice stock is considered within biological limits by the last ICES assessment)

The model is fully able to assess the national fishing fleet economic performance by measuring income, costs, economic indicators, capital value, profitability, benthic impact, as development trends as done in the routine EU STECF Annual Economic Report. However, this is not possible without further economic input data. Hence the gross added value accounted for in the present application (e.g. Figure 103) is a proxy based on the income from the sale of the landings from which fuel costs are subtracted. It is therefore only an approximation to the actual profitability.

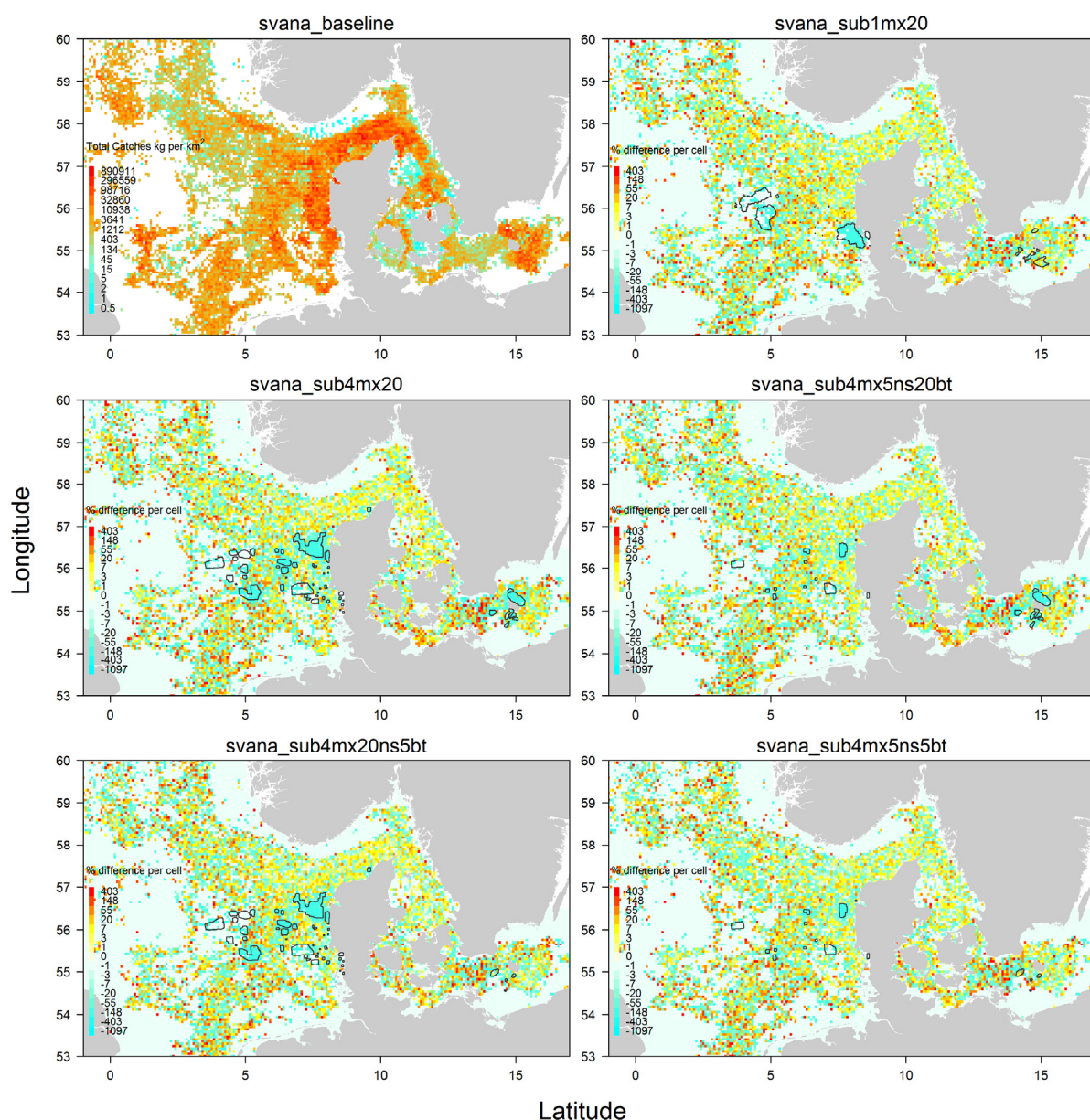


Figure 94 - Baseline spatial distribution of the Danish catches (landings + unmarketable fish) and the percentage of relative change (per grid cell of 36 km²) per scenario. Fishing efforts are given as the accumulated tons over the five-year simulation horizon averaged over the 20 replicates per scenario.

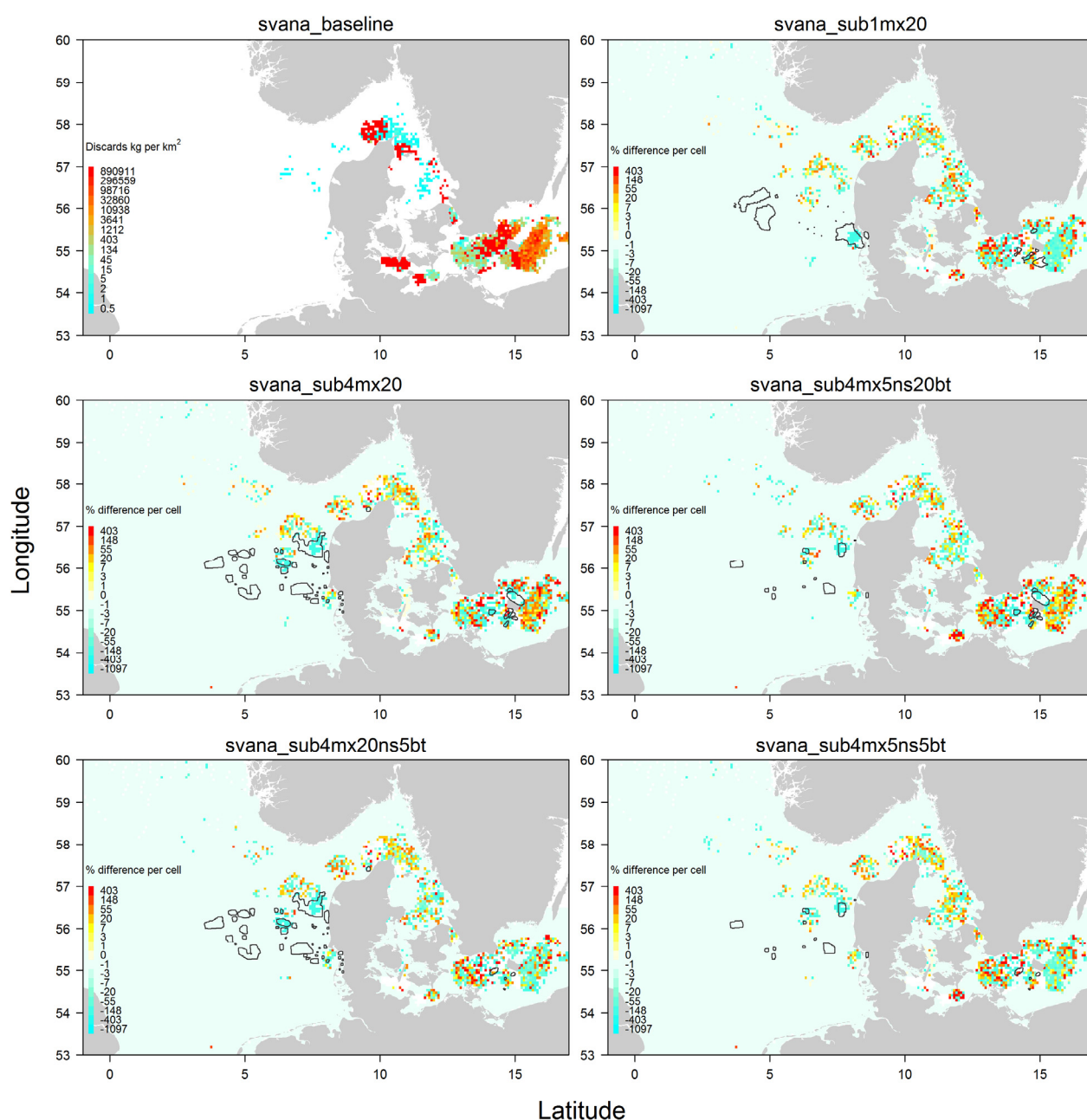


Figure 95 Baseline spatial distribution of the Danish unmarketable catches (formerly so-called “discards”) of all (but only) the species with explicit dynamics and the percentage of relative change (per grid cell of ~36 km²) per scenario. Catches are given as the accumulated tons over the five-year simulation horizon averaged over the 20 replicates per scenario.

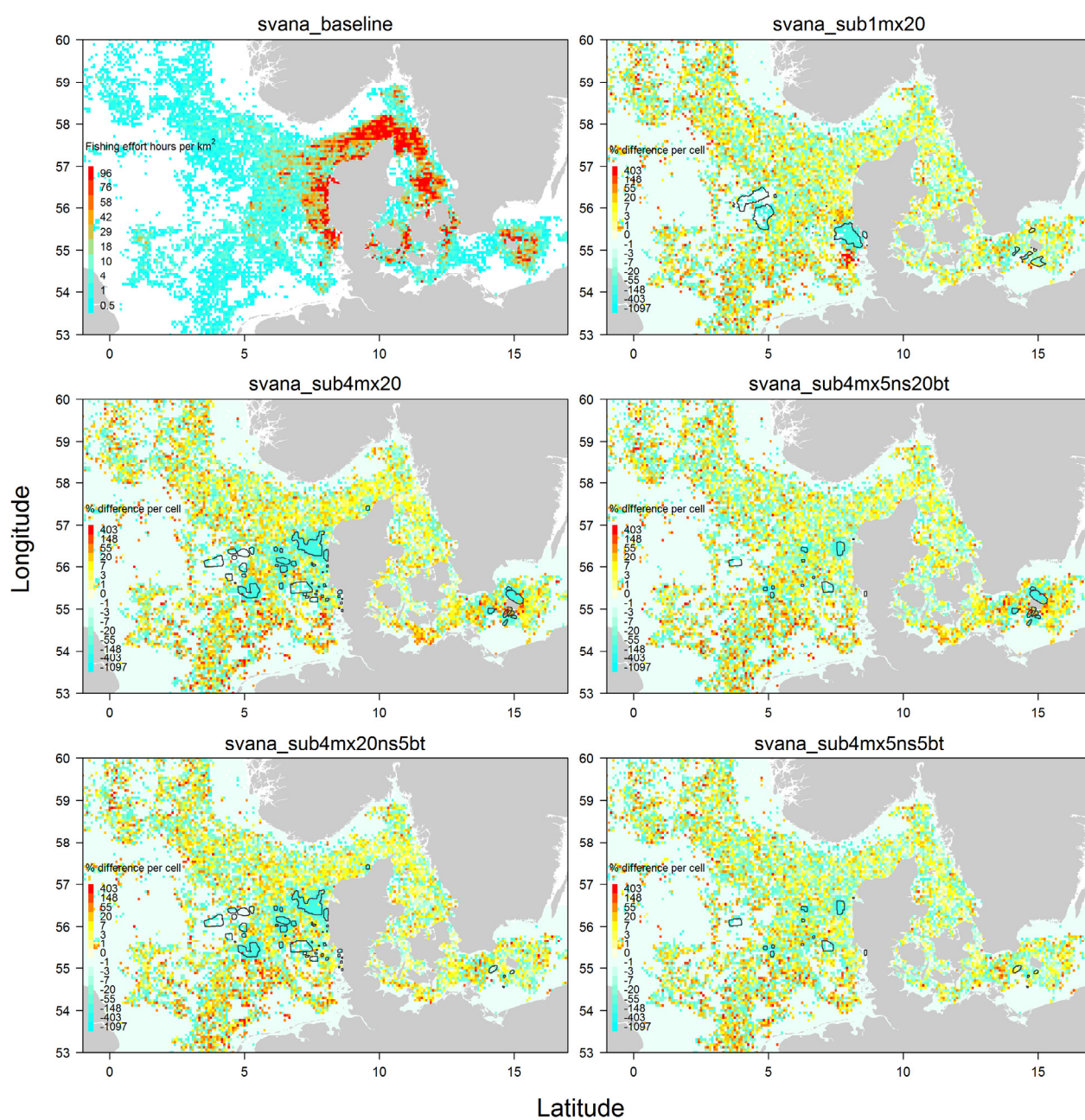


Figure 96 Baseline spatial distribution of the Danish fishing effort and the percentage of relative change (per grid cell of 36 km²) per scenario. Fishing efforts are given as the accumulated tons over the five-year simulation horizon averaged over the 20 replicates per scenario.

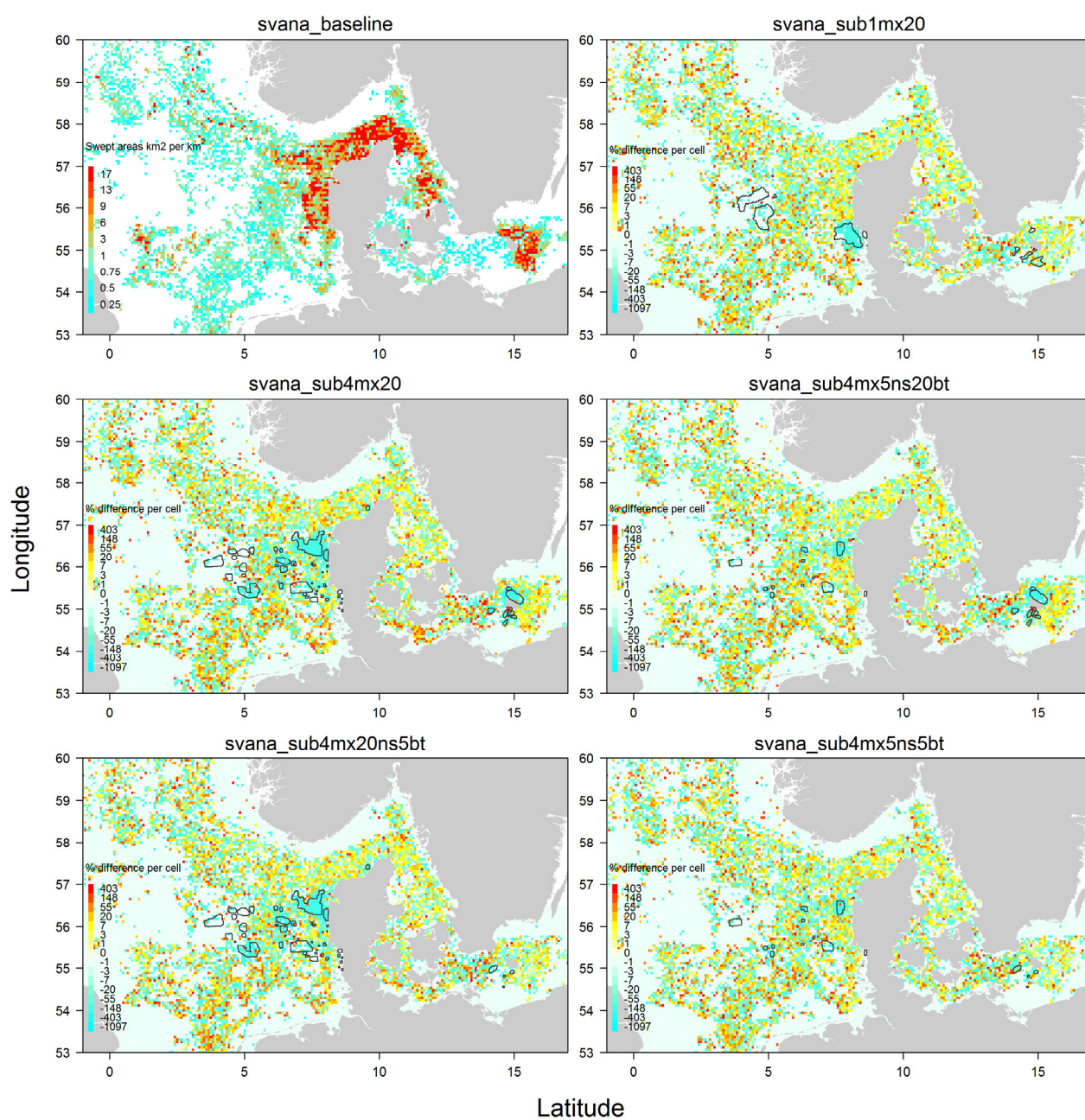


Figure 97 Baseline spatial distribution of the Danish fishing seabed swept area and the percentage of relative change (per grid cell of 36 km²) per scenario. Swept areas are given as the accumulated km² over the five-year simulation horizon averaged over the 20 replicates per scenario.

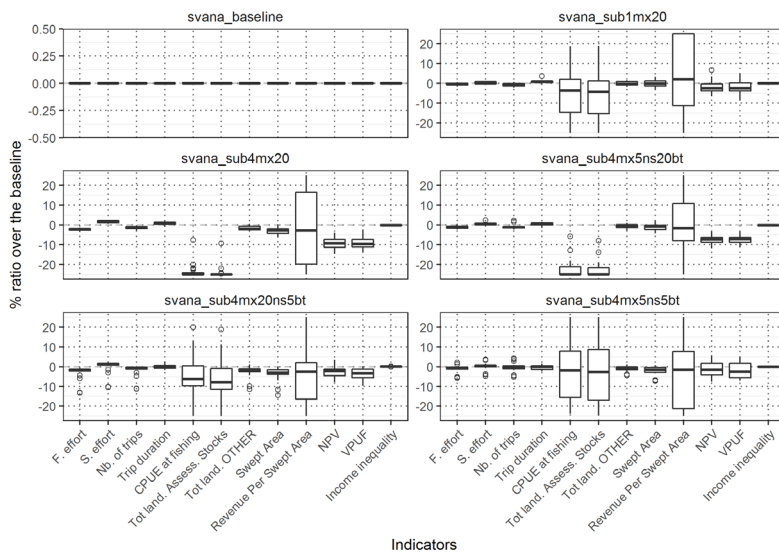


Figure 98 Comparison of aggregated scenario outcomes (20 stochastic replicates per scenario) on the vessel performance indicators (percent relative to the baseline) for all simulated vessels involved in the Danish fisheries. The percentages are relative to the baseline condition.

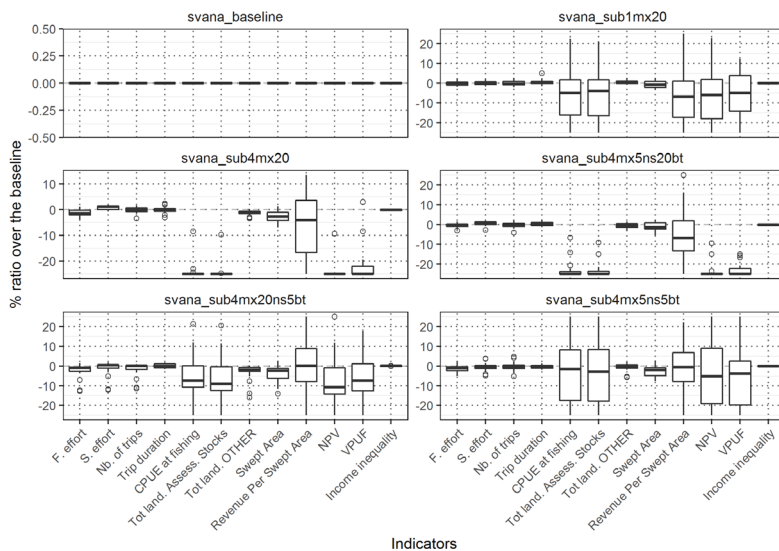


Figure 99 Same as Figure 98, but for selected vessels with bottom contact gears and visiting the Baltic side (149 vessels in ICES subdivisions 22-32).

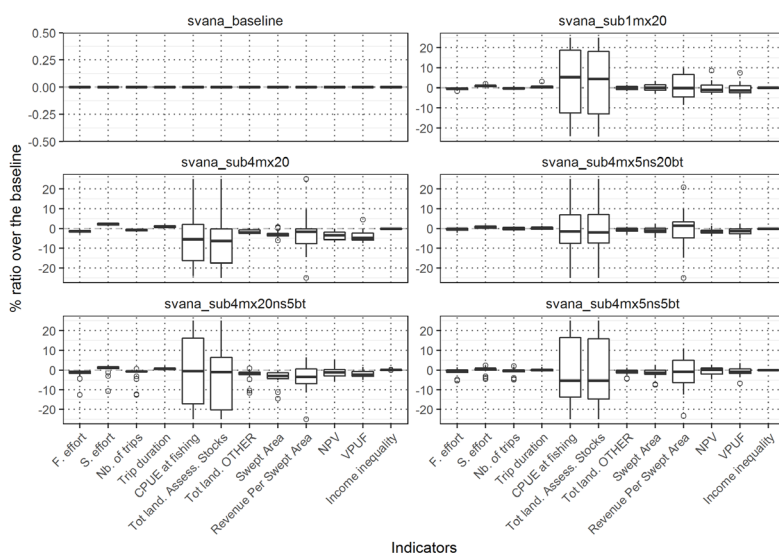


Figure 100- Same as as Figure 98, but for selected vessels with bottom contact gears and visiting the North Sea side (370 vessels in ICES IV and IIIa).

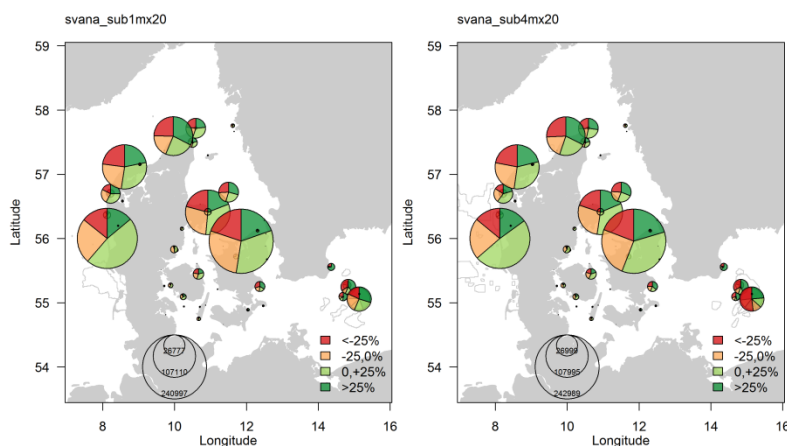


Figure 101 Class of vessels affected negatively or positively by the scenarios binned in 4 classes (>-25%, -25% to 0, 0 to +25%, >25% in income from landings) looking at the gain/losses on ports.

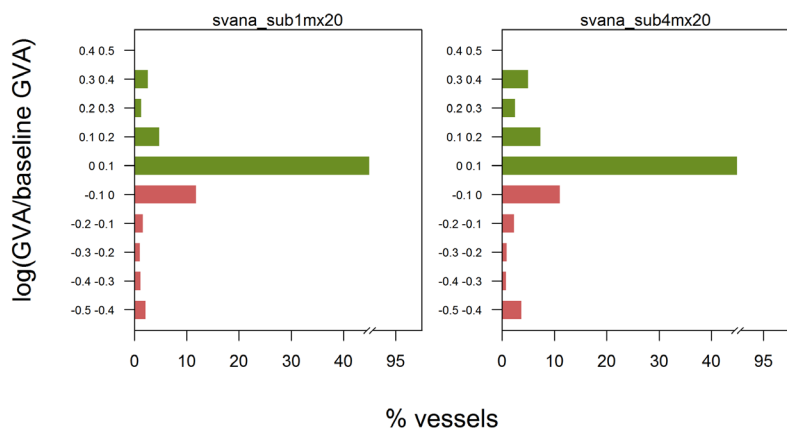


Figure 102 Percentage of vessels per ratio of GVA (in euros) at the time horizon of each scenario (a green bar represents a gain compared with the baseline situation, whereas a red bar represents a loss). The panels represent different scenarios described in the core text.

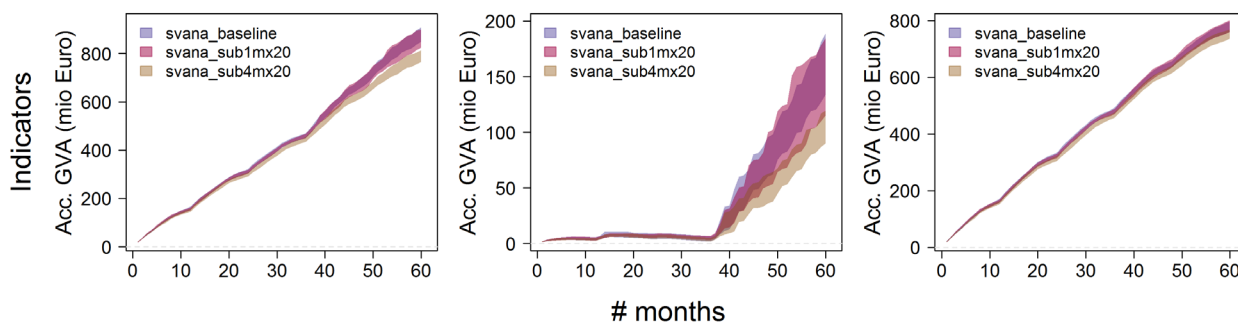


Figure 103 Accumulated revenue (GVA) per selected set of vessels (left- All simulated vessels, middle – vessel fishing in the Baltic Sea, right – vessels fishing in North Sea) per month over the simulation period up to the horizon time (month 60 in 2019) when focusing on the Danish fisheries (20 stochastic replicates per scenario).

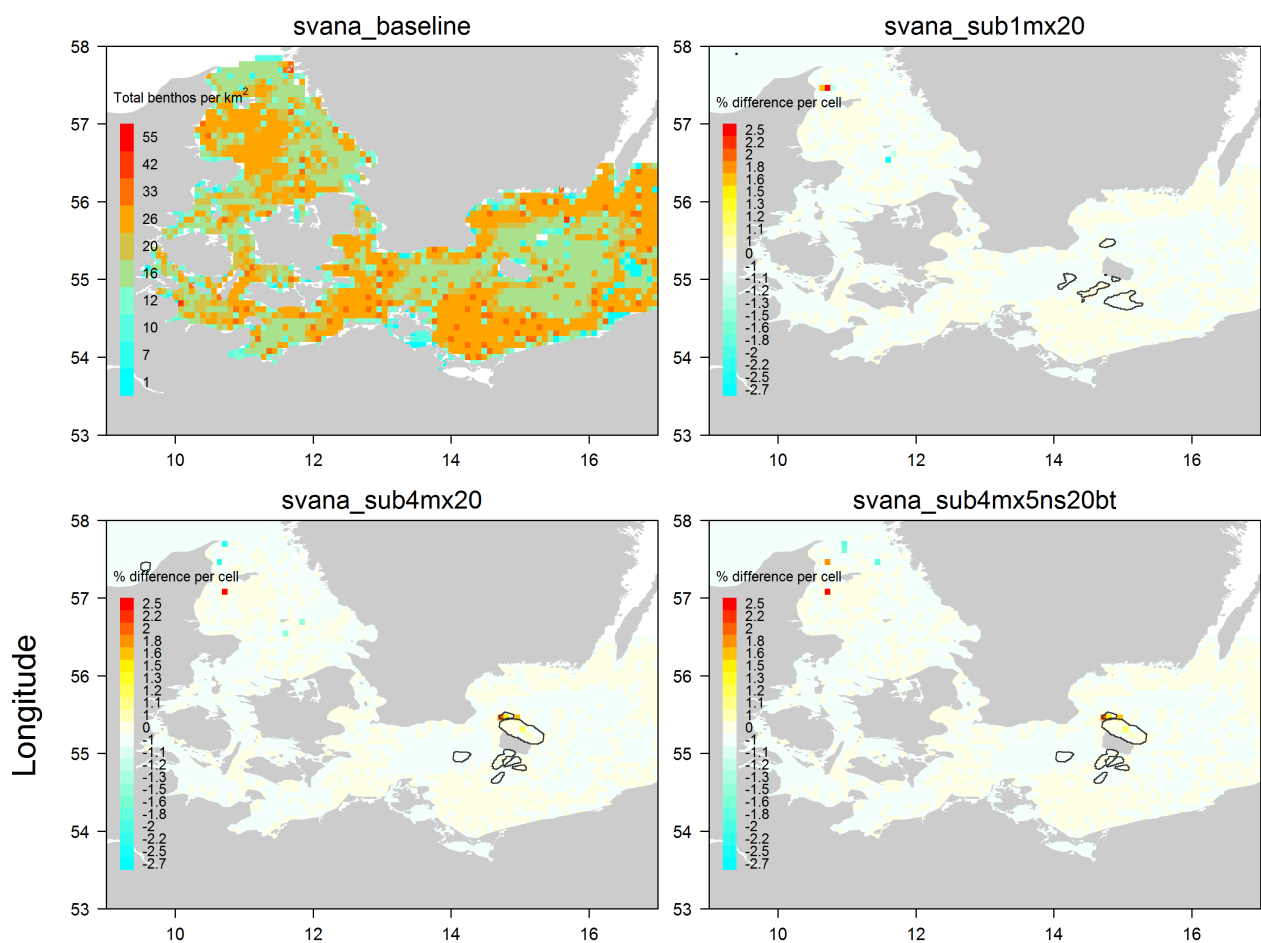


Figure 104 Baseline spatial distribution of the seabed benthos biomass informed on the Baltic Sea side and Kattegat and the percentage of relative change per scenario. Biomasses are given as the accumulated tons over the five-year simulation horizon averaged over the 20 replicates per scenario.

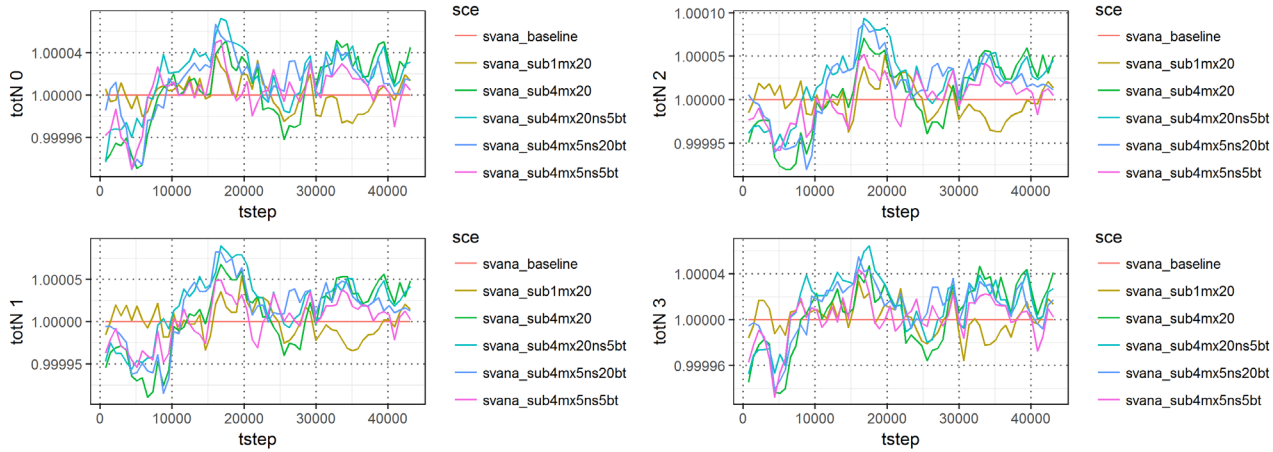


Figure 105 Relative change in total biomass of Baltic seabed benthos for 4 functional groups (0: Polychaeta, 1: Malacostraca, 2: Bivalvia, 3: Echinoidea) projected over the 5 years period (tstep is in hours) for each scenario (sce) expressed relative to the baseline scenario (i.e. bottom line at 1). Note that the effect on y-axis is very small because the surface impacted by the closure is small compared to the entire basin surface area (Kattegat, Western Baltic and Central Baltic). Curves give the median values over 20 replicates per scenario.

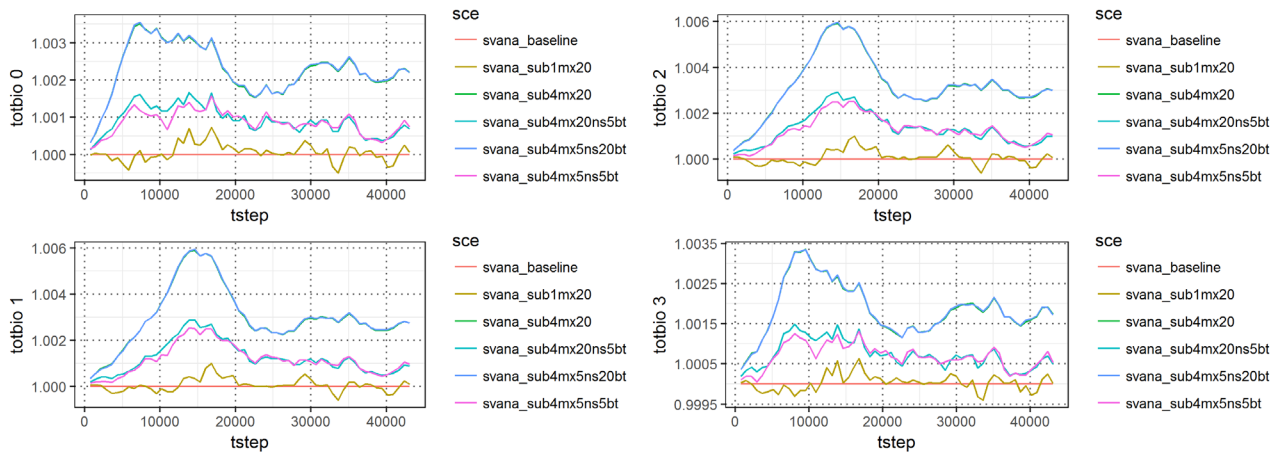


Figure 106 Same as Fig. 4.12 but only looking inside the potentially restricted areas.

10. Discussion of model results

The overall context for the modelling exercises has been to identify gaps in protection of important marine habitats and identify possible area for further establishment of MPA's. It has also been important to identify conflicts between human use and potential new MPA areas and suggest solutions with minimum economic consequences.

10.1 North Sea

In the North Sea and Skagerrak, Zonation locates the highest overall conservation value in areas along the coast of Jutland and in the most southwestern part of the Danish EEZ. When adding economic value, the high value of the fishery in the Skagerrak and adjacent to the Wadden Sea makes these areas less suitable. Marxan provides a similar overall pattern, but suggest a system of many smaller sites once economic value is included. The southwards gradient is likely influenced by the choice of connectivity parameter. Avoiding conflicts with human use as well as possible during the selection of suitable sites, has a strong influence on the results. By avoiding conflicts, the selected sites are moved to less suitable areas, so that either a larger area is required to fulfil the targets or the targets cannot be reached.

Site selection tools like Zonation and Marxan are better to analyse complex spatial data than humans, but they are of course data dependent. The available spatial data is in varying quality, the limitations are partly of qualitative nature, but also resolution and coverage change from topic to topic. When collecting the information it was noted that

- 1) Information on the present state of macro-benthos communities is limited from the Danish part of the North Sea and Skagerrak,
- 2) Geological survey lines in some areas were sparse,
- 3) Information about the distribution of many seabirds, harbour seals and grey seals was incomplete or missing,
- 4) Some data are not updated recently and might not present the current situation (Minke whale white beaked dolphin data from 1994 and 2005, soft bottom assemblages); other data was inhomogeneous (Harbour Porpoise),
- 5) It was difficult and time consuming to get up to date official data of all human activities. Where this was not possible, in some cases older and not official data could be used.

To decrease the influence of these gaps, surrogate layers were added based on physical and chemical properties of a habitat or known relationships between organisms. The missing information on reliably spatial distribution of soft bottom fauna is particularly important to remember when assessing the modelling results, as this is one of the ecosystem components not currently protected. The present handling of soft bottom communities as a proxy described by depth zones and seabed sediments must be regarded as a first suggestion. To improve the suggestions for representative MPA areas covering the soft bottom feature more sampling data is definitely recommended (especially in Skagerrak) to make a proper classification into different communities according to salinity, depth and sediment composition and taking the present impact of human use into account as well.

Instead of using the simple connectivity algorithms of the site selection tools, the connectivity was modelled in more detail including hydrographic data, which reflect the dominating northwards going current patterns in the North Sea. This has some clear advantages compared to the recommendations in Wolters et al 2015, where connectivity is just a matter of different distances regardless of dominating drift patterns. As suggested by Magris et al. 2015, the sourciness ("*reflecting a given areas ability to feed reproductive elements to other equal habitats*"), "betweenness" (connection between the selected sites) and local retention within a habitat area can be calculated for the relevant habitats and communities and be included as separate layers in the site selection tools.

However in the present setup, only the sourciness could be included, which must be considered when assessing the model output in the further planning process. So only a given ability of an area to feed reproductive elements to other equal habitats within the analysis area were considered while neither the ability for an area to restock itself nor the transboundary connectivity drift of reproductive elements from foreign MPAs and ability to stock the MPAs in Kattegat were included. These emittances skew the selection towards the SW North Sea. One could argue that the present connectivity setup favours a self-contained local sea area in this case the Danish North Sea and Skagerrak and not a more resilient regional network of protected areas. It was necessary to prioritize selected aspects due to the size and complexity of the overall exercise. However, it is recommended to analyse the connectivity more completely within a relevant study area. Such an extended study would in the same way increase the information about the representability of the suggested sites.

When avoiding conflicts as far as possible, areas less optimal for the conservation get selected and as a consequence Marxan selects larger areas. In theme 2 with the target 20% the selected the area is 50% bigger when avoiding conflicts than when including conflicts. Since other activities than just fisheries are considered as conflicts, this approach can be the reason that the scenarios with conflicts do not lead to a better situation for fisheries. Output from decision support tools like Zonation and Marxan are not meant to provide the final solution to a planning problem, but must be seen as providing information facilitating the planning process. Besides spatial data, the tools need input which reflects existing environmental protection and blue growth policies. Such information is needed to determine the relative weight the data layers representing different aspects of the ecosystem and of human activities. In this study the decision was made to weight the single economic sectors equally, while excluding some areas, such as cables, pipelines and windmill parks, from being selected. This gives fisheries a relatively low weight. It is therefore recommended to test additional scenarios giving the human uses different weights and e.g. being less restrictive about cables and pipelines.

10.2 Baltic Sea

In the area around Bornholm, Zonation in all three themes identifies the areas to the south and south west of the island to be the most ecologically valuable. When including economics and pressures, and excluding the area claimed by Poland, Zonation also includes the area between Christiansø and Bornholm among the most valuable areas. Marxan provides a very similar overall picture, albeit with much more detail in the particular areas selected. Avoiding conflicts with human use as well as possible during the selection of suitable sites, has a strong influence on the results. By avoiding conflicts, the selected sites move to less suitable areas, so that a larger area is required to fulfil the targets.

Using Displace to calculate the consequences of the 20% closure scenario proposed by Marxan revealed that the suggested closures generate a small reduction in the fisheries incomes and catch in the North Sea, but a substantial loss in the Baltic, where some of the vessels did seem to lack alternative fishing opportunities.

Site selection tools like Zonation and Marxan are better at handling complex spatial data than humans, but they are very much data dependent. Even though the data availability in general is good, the available spatial data are of varying quality, and resolution and coverage change from topic to topic. When collecting the information it was noted that

- 1) Limited information about the soft bottom fauna was available from the Danish part of the Baltic Sea around Bornholm
- 2) No information about fish species richness and abundance is available from untrawable areas.
- 3) Information on the distribution of coastal eelgrass and shallow brown algal vegetation and especial the lack of detailed bathymetry in the coastal zone exclude those habitats in the spatial modelling.
- 4) It was difficult and time consuming to get up to date official data of all human activities. Where this was not possible, in some cases older and not official data could be used.

To decrease the influence of these gaps, the spatial information was increased by involving surrogate layers. Especially the low resolution of the spatial distribution of soft bottom fauna is crucial in the assessment of the modelling results, since it is one of the ecosystem components not covered by the current network. New data should be collected and more advanced data handling capabilities should be used to outline the presence of biological communities as well as the present effect of human use within selected areas of interests for MPAs.

Compared to the North Sea, the hydrography of the Baltic Sea around Bornholm is less dynamic and the dominating current is less one-directional. Consequently, the layers describing the connectivity parameter “sourciness” shows a more even distribution than in the North Sea. It has to be kept in mind that also for this area the analysis is limited to the Danish part, so that the setup favours a self-contained Danish sea area and not a more regional network of protected areas. However, it was necessary to prioritize the Danish area due to the size and complexity of the overall exercise.

When excluding conflicts, areas less optimal for conservation get selected and as a consequence Marxan selects larger areas. In theme 2 with the target 20%, the selected area is 58% bigger when avoiding conflicts. Since other human activities than fishing are considered as conflicts, this approach can be the reason that the scenarios with conflicts do not lead to a better situation for the fisheries. It is therefore recommended, to test different weighting between human activities, especial to remove the strict exclusion of some human uses.

10.3 DISPLACE

DISPLACE predicts the impact of fishing on the biomass and distribution of benthos if benthos density data are available. Currently these data are only available in the Baltic. However, few samples were available from the Baltic around Bornholm. With these caveats in mind, we predict a very modest long term benthic biomass gain in the west and central Baltic after an initial loss in Scenario 2 (20+20%).

The results depend on the assumptions of the model approach and the specific input data. Therefore, particular attention should be given to the following aspects:

- 1) The inherent uncertainty in assuming the same spatial distribution of fish stocks over time. Regarding the latter, the spatial distributions of the harvested populations were derived from scientific surveys in 2013-2015. Ongoing work is refining this aspect by using advanced spatial population modelling, potentially accounting for supplementary environmental factors (such as changes in temperature and salinity).
- 2) The way the population dynamics are simulated. In the current application the population dynamics were explicitly simulated for 11 stocks out of the 39 stocks that the simulated vessels could fish upon. Some of these stocks, such as cod and whiting, are known to prey on their own juveniles, and this may dampen their response to a closure, but such density-dependent effects are not included in the model.
- 3) The benthos module of DISPLACE was parameterized with results of analyzing benthos data gathered outside the North Sea.

We would furthermore expect the demersal species to interact indirectly by feeding more on benthos, generating an increase in benthos depletion within closed areas. At this stage, the knowledge is too scarce to model this effect and foresee what the implications of changing relative fish abundance would be on the benthos, which is already impacted by direct mortality from bottom-contact gears. Other unknowns are the effects on non-commercial species caused by by-catch and habitat disturbance. We have taken the first steps towards an integrative approach by incorporating the impacts of seabed abrasion on the benthos biomass in the Baltic zone.

10.4 Uncertainties

Output from decision support tools like Zonation and Marxan are not meant to be taken literally, but should be considered as information that can facilitate the planning process. Besides spatial data, the tools need input which reflects the political position for environmental protection and blue growth. This information is needed to weight the data layers representing different aspects of the ecosystem and human activities. In this study the decision was made to weight the single sectors equally, and to assume that some human uses such as wind parks and oil and gas installations would exclude the establishment of MPAs. This gives fisheries a relatively low weight. This very basic approach was compensated by providing several scenarios, e.g. including and excluding human activities. For the ongoing political and administrative process, it is necessary to keep the limitations of the results in mind and consider a future extended and improved analysis, optimally closely linked to the planning so that the models are updated according to the requirements

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12. Annexes

Annex 12-1 IBMlib

IBMlib is a modelling framework for connectivity calculations (Christensen et al, 2017), based on individual-based simulations with realistic hydrographic data. Individual-based simulations track a set of representative individuals of a species for a period of their life, and thereby transport patterns between habitats can be mapped.

IBMlib is designed and programmed according to modern object-oriented principles. This implies that IBMlib is not only able to represent one species at a specific location with a specific hydrographic data set, but can easily be extended to address new species, new mechanisms coupled to new hydrographic data set. In this way IBMlib has been developed from scratch by DTU over the last 10 years, proving its worth in very diverse projects. IBMlib is written in Fortran, which is still the programming language giving best computer performance. Lately, graphical interfaces to IBMlib are also being added. IBMlib is being distributed as open source (IBMlib, 2017), so that everybody can freely develop or verify the code.

The IBMlib design principle is shown in the figure below; the core idea is that biology, hydrography and scientific tasks are kept strictly separate according to a well-defined protocol; thereby each part can be replaced by alternatives, without having to change the rest, and each part can be developed independently from the rest. The organisms in IBMlib is represented by a biological module, which keep track of growth, behavior, survival and individual characteristics; the biological module can be simple, e.g. a passive particle, or more complex with many stages and growth described by detailed bioenergetical models. Any hydrographic data set can be attached to IBMlib, with little effort; for Danish waters DTU Aqua often use state-of-art hydrography and biogeochemistry from DMIs operational model HBM-ERGOM. From an individual-based simulation IBMlib can automatically calculate a connectivity matrix between a set of habitats.

Individual-based simulations quantify how propagules are transported by currents to suitable settling habitats, reflecting their limited swimming abilities. This is the match-mismatch hypothesis illustrated below

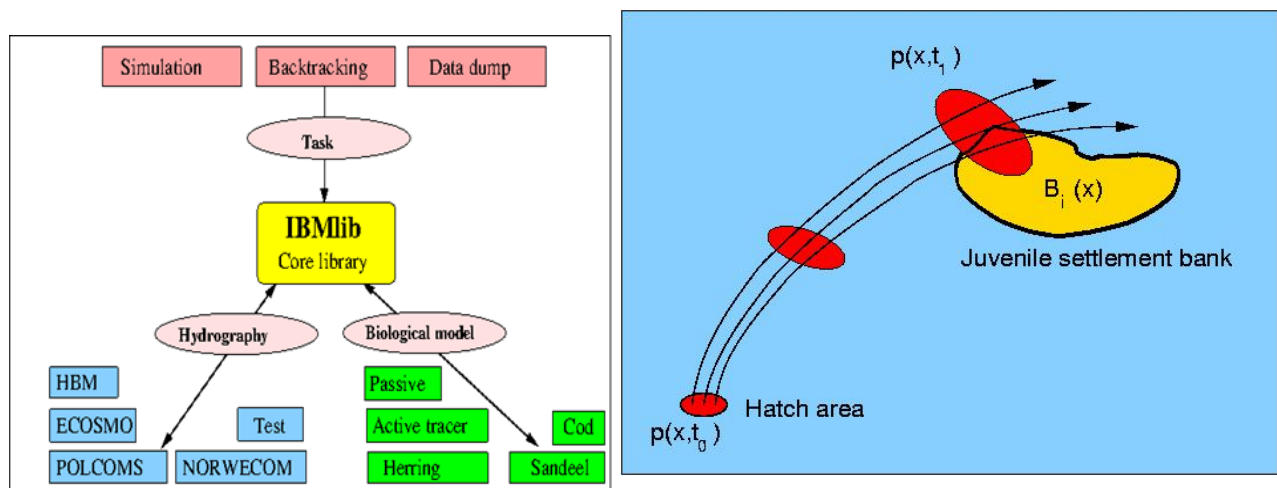


Figure 107 Left: Modular design principle of IBMlib with biology, hydrography and scientific task are kept strictly separate according a well-defined protocol. Right: Match-mismatch hypothesis for propagule transport. Larvae indicated as red patch being transported by mesoscale currents (arrows) and dispersed over time, due to small scale eddies and current shear. Only the fraction of hatched larvae over a suitable settlement habitat (yellow patch) at settling time will contribute to recruitment.

Individual-based modelling means that a representative set of larvae are modelled as independent organisms, rather than an Eulerian approach, where the average larvae is described by a probability distribution evolving in space and time. An individual-based simulation requires four components: a hydrographic model to provide the hydrographic conditions for pelagic phase of each propagule, a release a biological model for growth, survival and active behavior, and finally a settlement model.

Connectivity matrix calculation

The connectivity matrix T_{ji} is defined as the probability of being transported to habitat j , given that one starts at habitat i . We release a large number of agents (larvae) in each release habitat (see below) and then calculate the spatial distribution of the agents (larvae) at settlement time $P_i(x)$ as described above. The elementary transport matrix T_{ji} is then calculated by projecting $P_i(x)$:

$$T_{ji} = \int P_i(x) \mu(x \in \text{habitat } j) dx$$

where $\mu(\cdot)$ is 1 if the argument is true, otherwise 0. We refer to this as the connectivity matrix. T_{ij} gives the elemental connectivity between two habitat networks, a release and a settlement network. For many species, the release and a settlement network coincide. In the present work we define the release and a settlement habitat network at high resolution (c-square level). This means that connectivity between two regions A and B comprised by one or more c-squares can be computed from T_{ij} as

$$T_{AB} = \frac{\sum_{i,j} w_{iA} T_{ij} w_{jB}}{\sum_j w_{jB}}$$

where w_{iA} and w_{jB} are the weights of regions A and B in the high-resolution habitat network. We will apply this transformation to calculate e.g. how areas with different sediment types are connected.

The trait-based approach for connectivity assessment

Potential habitats are occupied by many organisms with very different biology. Many studies addressing a single species in a single area put large effort into parameterizing spawning, growth, behavior and settlement for that particular case. However, data are usually insufficient to convincingly parameterize all details of early life stages, and model predictions of the drift of the larvae of a particular species are therefore associated with significant uncertainty. The task of assessing drift for all biota present in a habitat appears at first sight to be monstrous. The trait-based paradigm addressed this challenge by focusing on the traits (biological properties) most important for the biological answer, rather than addressing each species. The central ansatz is that if the proper trait-ranges are sampled, then the community average and variability is better assessed, because the uncertainties associated with isolated species partially cancels. In this work we have addressed three major trait axes, pelagic duration, release time and vertical behavior to sample trait space.

Including connectivity data into marine protection planning

Proper procedures for applying connectivity data to situations of marine spatial planning is currently an active research area. A fundamental challenge is that the connectivity matrix T_{ij} is asymmetric and that it is a bilateral property rather than a habitat property that can be added to an objective function. Different schemes are proposed (see e.g. Magris et al, 2015) to overcome the challenge, all tries to map a matrix to a habitat-metric. One such map considered is the sourciness, i.e. how much does a habitat contribute to other habitats.

In the present work, due to time constraints, we are only addressing this connectivity metric. In terms of T_{ij} the sourciness is

$$S_i = \sum_j T_{ji}$$

And correspondingly for regional aggregations of high-resolution habitats.

HBM model Hydrographic dataset from the operational HBM model

To compute habitat network connectivity we are using data from the Baltic-North Sea ocean-ice model HBM (HIROMB-BOOS Model) in the operational setup by DMI (Danish Meteorological Institute). The model has been jointly developed by HBM consortium and used as an operational model in Denmark, Estonia, Finland and Germany. With two-way dynamical nesting, HBM enables high resolution in regional seas and very high resolution in narrow straits and channels. With its support for both distributed and shared memory parallelization, HBM has matured as an efficient and portable, high quality ocean model code.

HBM is a three-dimensional, free-surface, baroclinic ocean circulation and sea ice model that solves the primitive (Navier-Stokes) equations for horizontal momentum and mass, and budget equations for salinity and heat on a spherical grid that co-moves with the Earth's rotation. The vertical transport assumes hydrostatic balance and incompressibility of sea water. Horizontal transport is modelled using the Boussinesq approximation, where density differences are neglected in all but gravity terms. Higher order contributions to the dynamics are parameterized following Smagorinsky (1963) in the horizontal direction and a k- ω turbulence closure scheme, which has been extended for buoyancy-affected geophysical flows in the vertical direction (Berg and Poulsen, 2012; Poulsen and Berg 2012). The turbulence model includes a parameterisation of breaking surface and internal waves. Stability functions from Canuto et al. (2002) for the vertical eddy diffusivities of salinity, temperature and momentum have been applied. The model allows for fully two-way nesting of grids with different vertical and horizontal resolution, as well as time resolution. The numerical model implementation uses a staggered Arakawa C-grid and z-level coordinates, a flux-corrected horizontal advection scheme and free-slip conditions along the coastlines.

The HBM setup for the present hydrographic dataset has a horizontal grid spacing of 6 nautical miles (nm) in the North Sea and in the Baltic Sea, and 1 nm in the inner Danish waters. In the vertical the model has up to 50 levels in the North Sea and the Baltic Sea, and 52 levels in the inner Danish waters with a top layer thickness of 2 m. HBM is forced by DMI-HIRLAM with 10 m wind fields, sea level pressure, 2 m temperature and humidity and cloud cover. At open model boundaries between Scotland and Norway and in the English Channel, tides composed of the 8 major constituents and pre-calculated surges from a barotropic model of North Atlantic (Dick et al., 2001) are applied. Freshwater runoff from the 79 major rivers in the region is obtained from a mixture of observations, climatology (North Sea rivers) and hydrological models (Baltic Sea). At the surface the model is forced with atmospheric data from numerical weather prediction model HIRLAM (Petersen et al, 2005). The HBM setup performance has been validated on several occasions, e.g. Schmith and Borch 2013; Wan et al, 2012; Berg, 2012; Maar et al, 2011; She et al 2007a, She et al 2007b.

Annex 12-2 DISPLACE

DISPLACE is designed to predict how fishermen will respond to spatial and temporal closures, i.e. to the creation of protected areas from which certain gear types or vessel categories are excluded. To make this possible DISPLACE models the behaviour of individual fishing vessels by accounting for the factors that are important for fishermen's decisions about where to fish. The model predicts how fishermen will react to different fishing scenarios over a certain period of time (typically a 5-year horizon based on hourly time intervals) based on how individual vessels respond to changes in fish stock abundances and available fishing locations. The individual vessels can use different gears with gear selectivities specific to the target species they harvest. Sometimes they generate discards when the fish they catch are undersized (i.e. below the minimum landing size) or the quota has been exhausted. Catch rates depend on i) the location of the particular vessel. In case where population dynamics are explicitly simulated, catch rates are further modulated depending on ii) the métier⁵ in use (different métiers targeting different stocks); iii) the stock availability on the fished location (different catch rates result from the likelihood of encountering individuals of a given size constrained by gear selectivity) and iv) the habitat effect (some species are more likely to be caught when encountered on specific habitat types).

The model operates in hourly time steps and with a default spatial scale of 2×2 km. This is considered an adequate resolution for describing the spatial and temporal dynamics of human decision-making and fish population dynamics. Fish populations show seasonal dynamics and long-term spatial changes under various human pressures during their successive life stages. Fishermen take their decisions on where to fish based on the seasonal changes in the size and distribution of fish stocks, but are also influenced by economic and technical factors at the fishing trip scale, such as expected revenues and operating costs. The model time and space scales are appropriate for dealing with spatial management issues or marine spatial planning at large. It generates a synoptic view by aggregating all the small (fishing) operations at sea, at the same time including the spatial and temporal details. The approach is specifically suited for evaluating whether the benefits of spatial management compensate for the additional (economic and ecological) costs of displacing fishing effort to the surrounding areas.

DISPLACE includes a marine seabed habitat module that models benthos population dynamics for different functional groups of benthos. The model tracks the habitat-specific effect over time of different types of bottom contact gears and evaluates the depletion of the benthos density, where the benthos is able to recover in-between sequential fishing events.

DISPLACE supports the testing of EU common fisheries policy (CFP)-related fisheries management. It is spatial by nature and is primarily designed to test spatial plans that affects fishing in certain areas and seasons (months) for certain activities/métiers. The model has been applied to various regions and management options, for example in the Baltic Sea under a total allowed catches (TACs) and maximum sustainable level (FMSY) regime (Bastardie et al. 2016) or in the Adriatic Sea under a fishing effort control management scheme (Bastardie et al. 2017).

DISPLACE provides various outcome indicators shaped as time series or maps. The maps include the effect of fishing pressure on the stock indicators (stock abundance N , spawning stock biomass SSB , instantaneous fishing mortality F per stock, landings and discards per stock), the habitat indicators (biomass to carrying capacity ratio B/K , extent of area swept), the interlinked effect of the fisheries management and related fishermen decision-making on the economics of the fisheries (incomes from landings, gross value added GVA , energy efficiency), and socioeconomic indicators (annual economic report (AER) indicators e.g. net

⁵ A métier is defined as a fishing activity which is characterised by one catching gear and a group of target species, operating in a given area during a given season, within which each boat's effort exerts a similar exploitation pattern on a particular species or group of species. The species composition and size distribution in catches taken by any vessel working in a particular métier will thus be approximately the same. A métier is indicative of where and how boats work, not of the port of origin or landing.

profit, etc.). The outcomes can be summarized at various aggregation levels, from individual vessels to harbours, to entire fleets, or to nations.

The DISPLACE model is parameterised and operational for the fisheries in the Baltic and North Sea, among others. The details of the method (modelling from the coupled VMS6 data to logbooks, from Bottom International Trawl Survey data, etc.) and the general settings (individual vessel parameterization, etc.) used here are given in Bastardie et al. (2016).

DISPLACE version 0.9.9 was used (available online at www.displace-project.org; Figure 108). All the aggregated figures and plots are produced with a specific R package named “displaceplot” available online on the GitHub platform.

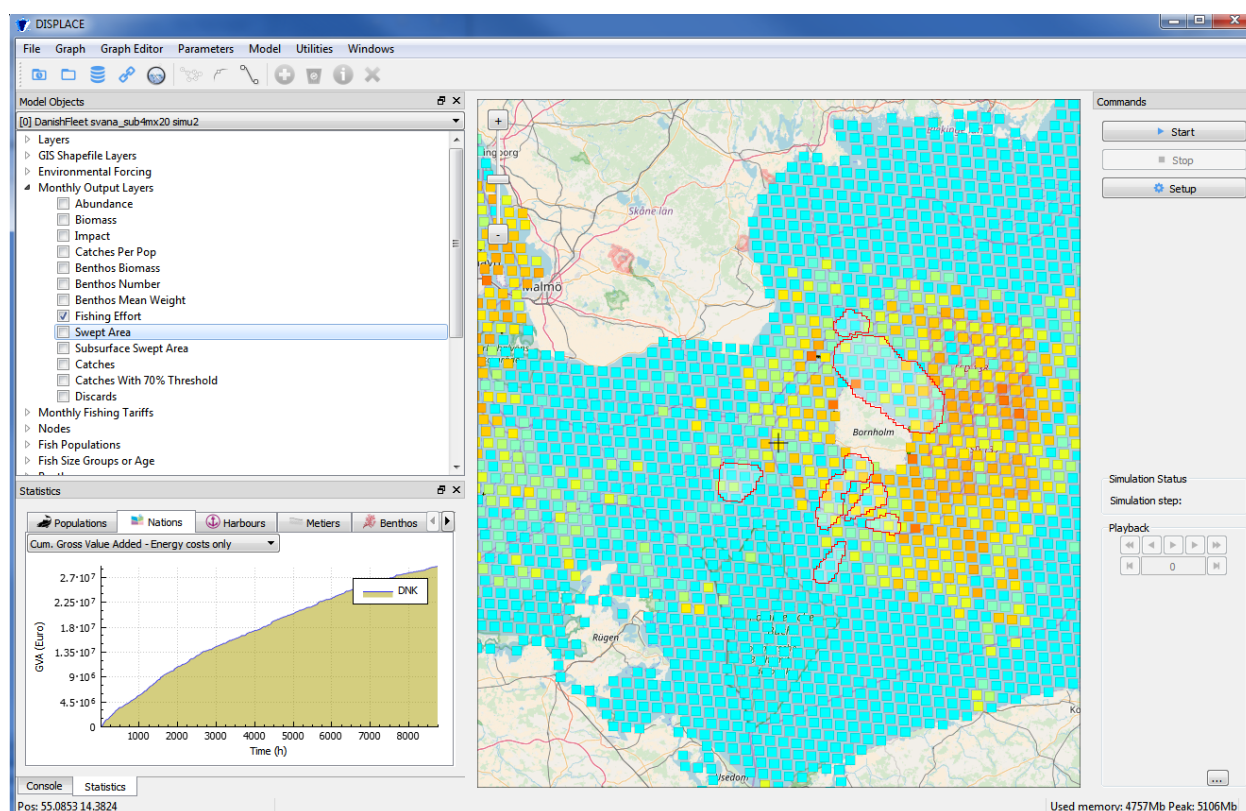


Figure 108 Screenshot of the graphical user interface for DISPLACE v0.9.9 (<http://displace-project.org/blog/download/>) showing “live” mode plots of tracked biological and economic variables, displayed simultaneously in a graphic time window and on a spatial map panel, with degrees of variable aggregation controlled from a hierarchical tree structure.

Example of setting up a closure scenario in DISPLACE

DISPLACE v0.9.9 procedure to set up the MST/MFVM DISPLACE scenarios e.g. scenario MST/MFVM_sub4mx20:

- i) Start a new DISPLACE

⁶ VMS: Vessel Monitoring System

- ii) Load 'DanishFleet' Graph 40 in Graph>Load
- iii) Load ArcGIS WGS84 shape files in File>import Shapefile, as many as required i.e. DISPLACE_MST/MFVMPProject\Input for DISPLACE\1_222324.shp
- iv) In 'Graph>Add penalties from Shapefiles', adjust closed_for_fishing specifications to the scenario (i.e. months=Feb and Mar, metiers = myfish FPO_DEF, GNS_DEF, OTB_DEF, OTM_DEF, PTB_DEF, PTM_DEF, SDN_DEF, SSC_DEF, shapes= 1_222324.shp, vessel sizes= all) and click ok
- v) Again, In 'Graph>Add penalties from Shapefiles', adjust closed_for_fishing specifications to the scenario (i.e. months= select all metiers; NST2_sub4_mx20_wgs84.shp, BHT2_sub4_mx20_wgs84.shp, vessel sizes= all sizes) and click ok, this will append to the previous step.
- vi) Save the Graph (i.e. Graph 411) in 'Graph>Save'
- vii) Load the Graph 411 again in 'Graph>Load'
- viii) Compute the shortest paths in a shortPaths_myfish_a_graph411 folder placed in \DISPLACE_input_DanishFleet with 'Graph>Create short paths' from DanishFleet\vesselsspe\vesselsspe_fgrounds_quarter1.dat. [This step is optional given no penalty has been added so far to the baseline shortPaths_myfish_a_graph40 can be directly re-used by copy/pasting in shortPaths_myfish_a_graph411]
- ix) Create a .dat scenario file MST/MFVM_sub4mx20.dat inspired from MST/MFVM_baseline.dat but with the DynAllocSce option 'area_monthly_closure' ticked, this option will make the closure dependent on combinations in the simulations i.e. a given vessel will be affected on locations if and only if banned metiers is TRUE and banned vessel size of this vessel is also TRUE on these locations. Quit DISPLACE or Graph> 'Clear Graph'

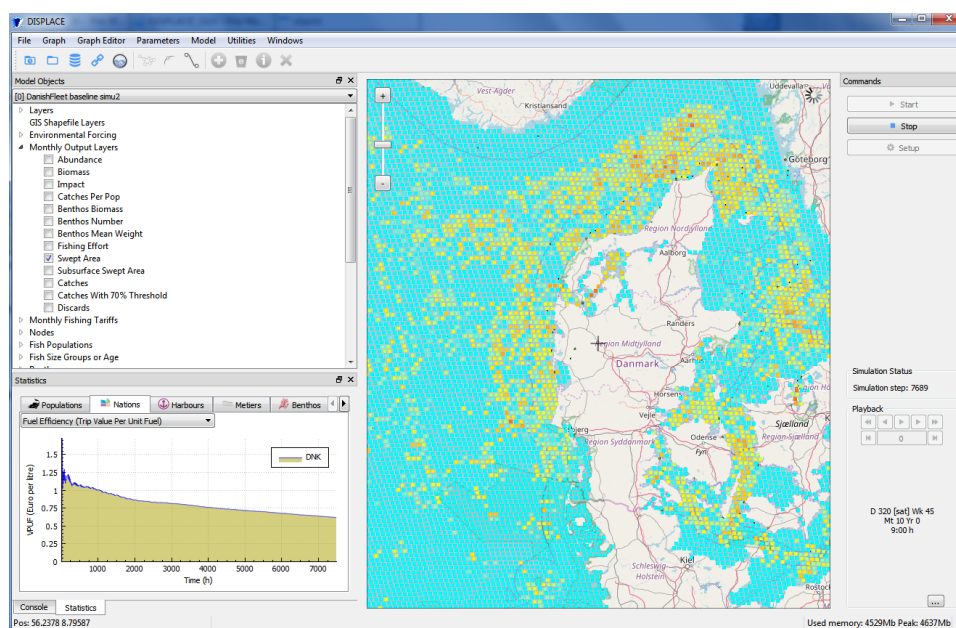
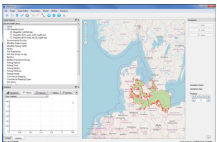
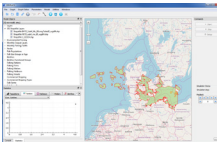
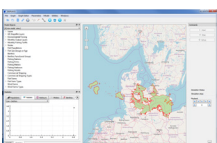
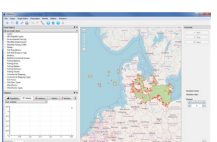
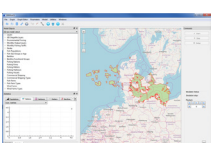
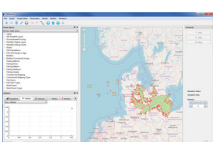


Table 4 Scenarios implemented on the Danish Fleet DISPLACE application described in the core text. Impacted fleet segment names refer to the EU Data Collection Framework classification, level 5.

| Scenarios | Fishing Closure and Marxan targets | Timing of closure | Dynamic displacement | Static (spatial) displacement | Impacted segments ⁷ |
|--|--|--|-------------------------------------|---|--|
| 1  | Area 1: ICES SD 22, 23, 24 (Baltic Cod closure) | Area 1: 1st of Feb to 31 of March | All areas - Danish vessels > 8 m | Others i.e. BE, DE, EE, FI, FO, FR, GB, IE, LT, LV, NL, NO, PL, SE | All areas – GNS_DEF, LLD_ANA, OTB_CRU, OTB_DEF, OTB_MCD, other, SDN_DEF, SSC_DEF, TBB_CRU |
| 2  | Area 1: ICES SD 22, 23, 24, (Baltic Cod closure) Area 2: North Sea 20% & Baltic 20% accounting for exclusions and economics | Area 1: 1st of Feb to 31 of March Area 2: all months | All areas - Danish vessels > 8 m | Others i.e. BE, DE, EE, FI, FO, FR, GB, IE, LT, LV, NL, NO, PL, SE | All areas – GNS_DEF, LLD_ANA, OTB_CRU, OTB_DEF, OTB_MCD, other, SDN_DEF, SSC_DEF, TBB_CRU |
| 3  | Area 1: ICES SD 22, 23, 24, (Baltic Cod closure) Area 2: North Sea 20% & Baltic 20% without accounting for exclusions and economics | Area 1: 1st of Feb to 31 of March Area 2: all months | All areas - Danish vessels > 8 m | Others i.e. BE, DE, EE, FI, FO, FR, GB, IE, LT, LV, NL, NO, PL, SE | All areas – GNS_DEF, LLD_ANA, OTB_CRU, OTB_DEF, OTB_MCD, other, SDN_DEF, SSC_DEF, TBB_CRU |
| 4  | Area 1: ICES SD 22, 23, 24, (Baltic Cod closure) Area 2: North Sea 5% & Baltic 20% accounting for exclusions and economics | Area 1: 1st of Feb to 31 of March Area 2: all months | All areas - Danish vessels > 8 m | Others i.e. BE, DE, EE, FI, FO, FR, GB, IE, LT, LV, NL, NO, PL, SE | All areas – GNS_DEF, LLD_ANA, OTB_CRU, OTB_DEF, OTB_MCD, other, SDN_DEF, SSC_DEF, TBB_CRU |
| 5  | Area 1: ICES SD 22, 23, 24, (Baltic Cod closure) Area 2: North Sea 20% & Baltic 5% accounting for exclusions and economics | Area 1: 1st of Feb to 31 of March Area 2: all months | All areas - Danish vessels > 8 m | Others i.e. BE, DE, EE, FI, FO, FR, GB, IE, LT, LV, NL, NO, PL, SE | All areas – GNS_DEF, LLD_ANA, OTB_CRU, OTB_DEF, OTB_MCD, other, SDN_DEF, SSC_DEF, TBB_CRU |
| 6  | Area 1: ICES SD 22, 23, 24, (Baltic Cod closure) Area 2: North Sea 5% & Baltic 5% accounting for exclusions and economics | Area 1 - 1st of Feb to 31 of March Area 2- all months | All areas - Danish vessels > 8 m | Others i.e. BE, DE, EE, FI, FO, FR, GB, IE, LT, LV, NL, NO, PL, SE... | All areas – GNS_DEF, LLD_ANA, OTB_CRU, OTB_DEF, OTB_MCD, other, SDN_DEF, SSC_DEF, TBB_CRU |

⁷ Only DCF level 5 described here but level 6 metiers accounted for in the simulations.

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